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ONR REPORT ACR-33

ARRANGEMENT OF GROUPS OF MEN AND MACHINES

CHAPTER VIII
of
HUMAN ENGINEERING GUIDE TO EQUIPMENT DESIGN

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ARRANGEMENT OF GROUPS OF MEN AND MACHINES

Robert M. Thomson
Bernard J. Covner
Herbert H. Jacobs
Jesse Orlansky

Dunlap and Associates, Inc.

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OFFICE OF NAVAL RESEARCH
Department of the Navy * Washington, D. C.

FOREWORD

This report was prepared for the Engineering Psychology Branch, Office of Naval Research, under Contract Nonr-1798(00), with Dr. Max W. Lund as project officer. It is a preliminary draft of material to be incorporated in the Human Engineering Guide to Equipment Design, now being prepared under the direction of a joint Services Steering Committee.

Users of this report are invited to submit comments for revising or adding to the information contained herein to Head, Engineering Psychology Branch, Office of Naval Research, Department of the Navy, Washington 25, D. C.

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INTRODUCTION

Problems of organization, arrangement, and design of compound man-machine systems represent a very large complex of decision-making problems. No entirely objective or adequate methodology for treating such problems has evolved and, because of the nature of decision problems in general, probably never will. Although formal techniques have been developed for coping with certain aspects of systems analysis, the role of individual judgment, insight, and inventiveness remains strong. The state of current practice in this field is such that different analysts working on the same problem are very likely to arrive at different solutions. In this sense, at least, the "science" of system organization and design is still an art.

The methodological framework which has been proposed for developing complex man-machine systems includes the following elements:

1. Formulation of the Problem: Description of the functional role (mission) which the proposed system is intended to fulfill, the environmental or other conditions within which the system is to operate, and any limiting constraints (minimum or maximum) which have been applied to system design, operation, or performance (requirements).

2. Establishment of Evaluative Criteria: Development of measures or indices which describe some of the performance characteristics of the system and which are relevant to, and can be employed in, the evaluation of proposed solutions to the problem.

3. Selection of Preliminary Designs: Development of one or more promising designs or solutions to the problem. These represent the alternatives which must be compared in terms of the criteria established.

4. Systems Analysis and Evaluation: Development and application of procedures for estimating the performance of competitive designs. In conclusion, selection of the design which offers the most effective solution to the problem.

Actual design practice, particularly that associated with the development of complex man-machine systems, varies enormously both in recognizing the need for a broad methodology as well as in the actual procedures employed in arriving at a final design. At one extreme, design selections appear to be made perfunctorily, suggesting that the methodological elements described above are performed intuitively or that they may even be disregarded. At the other extreme, a large set of design alternatives may be explicitly formulated in an attempt to exhaust the possibilities which are technologically feasible. Evaluative criteria are established on the basis of careful consideration of the functional requirements of the system, including the value structure of the people who are intended to benefit from it. Careful analytical and experimental techniques are applied to simulate and measure the behavior of the system under various anticipated operating conditions. The entire rationale underlying selection of the final design is made explicit.

Between these two extremes there exists a wide variety of methods of design. This is particularly true with respect to the evaluative criteria which are employed and the techniques which are used to describe the performance of alternative system designs. In some cases, extreme attention is devoted to the problem of selecting design criteria while qualitative methods or even personal judgment are utilized for ranking alternative designs on the basis of these criteria. In other cases, one or more criterion measures or perhaps some type of evaluative index is selected almost arbitrarily, whereupon elaborate numerical or analytical techniques are employed for developing a "figure of merit" for each possible design.

All other considerations aside, the most profound, complete, and rigorous methodological treatment should enable the closest approach to a "best" design. It is important to point out that the appropriate treatment will vary from problem to problem and even for various aspects of each problem. For example, the various design properties of the simplest man-machine systems are too many even to be enumerated. Most of these are of such trivial consequence as to be undeserving of even perfunctory analytical treatment. There will, however, generally be at least a few design properties which affect so strongly the performance and, therefore, the utility of the system that they warrant extensive and profound design investigation. The appropriateness of any investigative treatment, consequently, will depend on the anticipated importance of any given design property. It must also depend on such considerations of expediency as the time and effort which can be made available for such study, together with the foreseeable complexity of the analytical problems.

For purposes of organization, available techniques might be categorized by their dependence upon arbitrary judgment. Purely qualitative methods generally involve both the arbitrary selection of criteria and the arbitrary selection of design properties for satisfying these criteria. This is not to say that effective system design cannot be accomplished in this way, but rather that this type of "engineering" trades almost exclusively upon experience and intuition and is, therefore, most susceptible to error.

Semiquantitative and quantitative methods approach more closely traditional engineering practice in that they both involve the concept of performance measurement, depend more heavily upon observational and experimental technique, and employ formal methods for developing and describing complex relationships. Semi-quantitative methods require more judgment in the selection of design choices by way of requiring compromises between various measures of performance to be made intuitively. Beyond this, quantitative procedures of systems analysis are available which restrict the role of judgment chiefly to the selection of higher order criteria, an area where agreement is probably easier to achieve. All of these procedures, of course, require the exercise of judgment with regard to forecasting future environments, operating conditions, costs, component capabilities, etc.

The choice of the most appropriate technique to use in any systems analysis is not entirely clear. It is generally believed that the best engineering involves the least amount of arbitrariness with respect to design rationale. On the other hand, the application of rigorous treatment increases substantially the cost, time, and difficulty of systems analysis. This suggests that qualitative procedures are probably best applied for resolving a large number of superficial problems which enter into any complex system design problem. More formal methods are probably best reserved for studying those design aspects which are believed to have profound or at least important significance with respect to mission accomplishment.

PART 1
LAYOUT OF COMPARTMENTS

The layout of compartments is considered here from the viewpoint of its effect upon human performance. For this purpose, it will be assumed that the following factors are fixed (at least provisionally):

1. Mission of the system and specific mission of this subsystem.
2. Design of individual consoles (controls, displays, etc.).
3. Function of individual equipment items.
4. Number of equipment units.
5. Number of personnel and their assigned duties.

The following steps may be taken as a general guide to layout problems (9,10):

1. Plan the whole and then the details.
2. Plan the ideal and, from it, the practical.
3. Follow the cycles of layout development and make the phases overlap.
4. Plan the process and equipment around the system requirements.
5. Plan the layout around the process and equipment.
6. Plan the building around the layouts.

In other words, the development of each successive step tends permanently to solidify or "firm up" the preceding decisions. Because of this interaction, it is important to consider the entire plan before making any initial decisions. Almost every field of engineering will accept this procedure as an ideal one. All too frequently, however, certain structural or space limitations are rigidly defined from the outset. The problem therefore resolves itself into a process of optimizing the layout within the given restrictions.

Compartment size and shape will depend primarily on the total size and shape of the working units which must go into the compartment. Working space tolerances within the compartment are determined by both personnel and equipment requirements.

1.1 COMPARTMENT SIZE AND SHAPE

1.1.1 Effects of Human Body Sizes and Dynamics

The human body dimensions which most directly affect compartment size and shape are listed in Tables I, II, and III. The dimensions which have been selected are the 5th percentile (small man), 50th (median man), and 95th (large man) in the adult male Air Force population. Values are given for seated and standing men, both when erect and when slumped.

TABLE I
Standing Dimensions (inches)*

Dimension	5th Percentile		Median		95th Percentile	
	Erect	Slump	Erect	Slump	Erect	Slump
1. Standing height	65.2	64.0	69.1	67.9	73.1	71.9
2. Eye height	60.8	59.6	64.7	63.5	68.6	67.4
3. Shoulder (acromion) height	52.8	51.6	56.6	55.4	60.2	59.0
4. Elbow height	40.6	39.4	43.5	42.3	46.4	45.2
5. Knuckle height	27.7	26.5	30.0	28.8	32.4	31.2

*Erect dimensions were obtained from Hertzberg, et al. (7). Slump dimensions are 1.2 inches less than the erect data (4). To allow for shoes, add 1.1 inches.

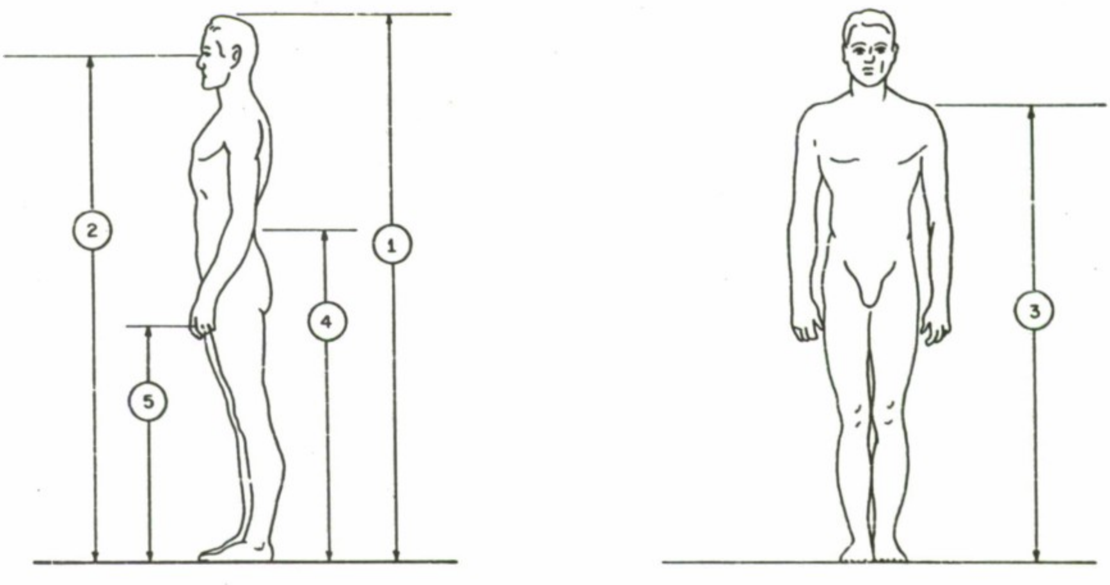


TABLE II
Seated Dimensions (inches)*

Dimension	5th Percentile		Median		95th Percentile	
	Erect	Slump	Erect	Slump	Erect	Slump
1. Sitting height	33.8	31.8	36.0	34.0	38.0	36.0
2. Eye height	29.4	27.4	31.5	29.5	33.5	31.5
3. Shoulder (acromion) height	21.3	19.6	23.3	21.6	25.1	23.4
4. Elbow height	6.6	4.9	9.1	7.4	11.5	9.8
5. Thigh clearance	4.5	-	5.6	-	6.8	-
6. Knee height (above floor)	20.1	-	21.7	-	24.4	-
7. Buttock-knee length	21.2	-	23.6	-	25.4	-
8. Buttock-leg length	39.4	-	42.7	-	46.7	-
9. Hip breadth	12.7	-	13.9	-	15.4	-

*Erect dimensions were obtained from Hertzberg et al. (7). Slump dimensions are corrections of erect data, allowing -2.0 inches for items 1 and 2 and -1.7 inches for items 3 and 4. See Ely et al. (4).

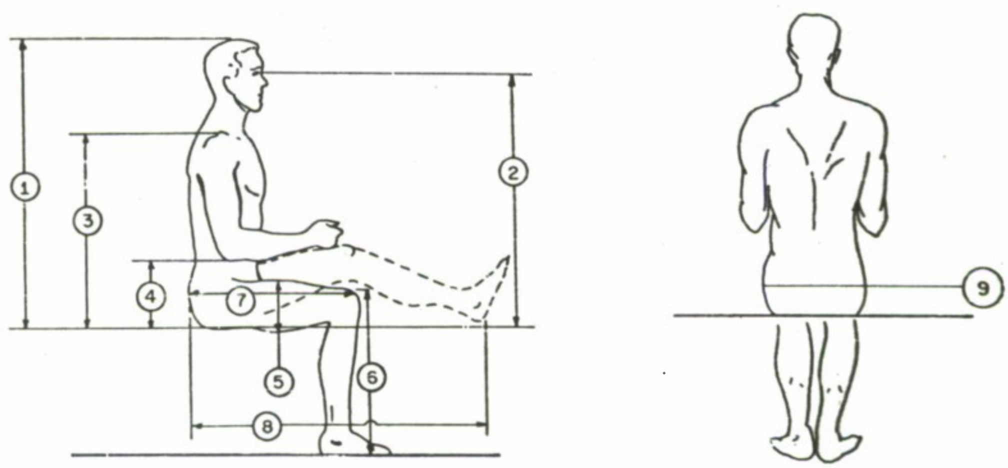
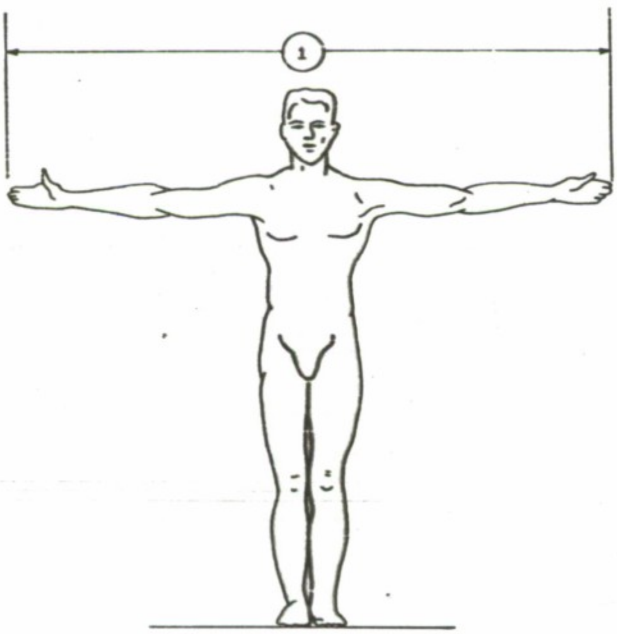
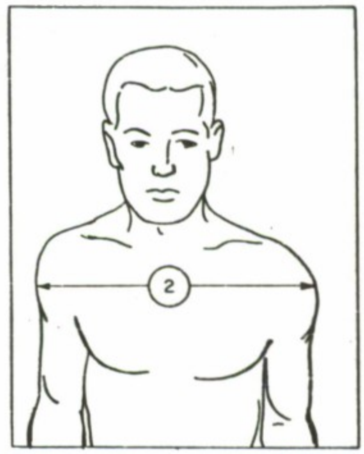
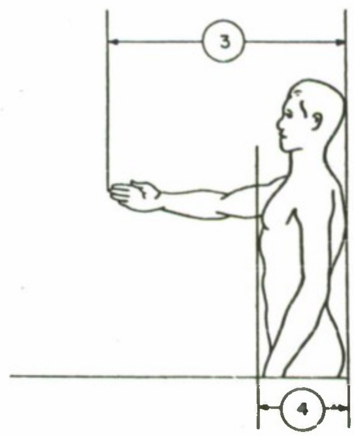


TABLE III
Miscellaneous Dimensions (inches)

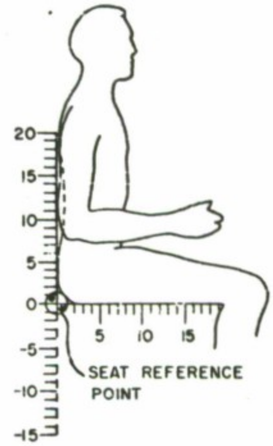
Dimension	5th Percentile	Median	95th Percentile
1. Arm span	65.9	70.8	75.6
2. Shoulder breadth (bideltoid)	16.5	17.9	19.4
3. Forward arm reach (from seat back or wall)	31.9	34.6	37.3
4. Chest depth	8.0	9.0	10.4







Seated dimensions are given with respect to the seat reference point, since the distance of the seat pan from the floor varies according to the type of seat being used.



Although the data presented in the tables describe the nude figure, they are acceptable for a lightly clothed man. No attempt has been made to list allowances for clothing because of the wide variety of uniforms and special equipments worn throughout the armed forces. It is recommended that when special clothing or equipment is worn, a mockup be made and space tolerances be determined empirically. Note that heavy clothing or encumbering equipment has two important effects on nude dimensions:

a. It increases the static dimensions, e.g., trunk thickness, thigh clearance.

b. It decreases the dynamic dimensions, i.e., arm span, arc of leg movement, forward arm reach, because it interferes with freedom of motion. The wearing of gloves (unless very thin ones) greatly reduces manual dexterity, and this consideration will tend to override any decisions based on muscular limitations.

In addition to the static measurements, we must also consider the total area bounded by the operator when he moves. When two or more operators are working side by side, the minimum space which should be allotted each operator is the "envelope" which he fills while working; these are the optimum manual and pedal areas as described in Chapter V, Part 2 of this Guide (4).

The following precautions apply to the use of lateral dimensions:

a. Use the 95th percentile when the size of the operator to be stationed at any particular unit cannot be predicted in advance.

b. Add 4 inches to either side to allow for normal "elbow room."

Generally, 24-inches lateral room has been regarded as sufficient; however, this dimension provides space only for operators seated side by side at a table and does not take into account activities such as rotary movements requiring several pounds torque when the forearm is used.

1.1.2 Effects of Crew Size

A large crew imposes certain conditions on design not required by a small crew. For instance:

a. communications

As the crew size increases, unaided voice communications decrease in effectiveness and reliability.

b. physical access

Additional space must be provided for access from the main compartment entrance to and between the various work stations. For the lone operator, this can be reduced to a minimum (viz., airplane cockpit). For accesses through which personnel must sometimes hurry, additional clearances should be provided.

c. environmental conditions

1) Illumination: Illumination requirements become more complex for a large crew, especially where these requirements vary among operators. General lighting must be provided for the overall area, aisles, exits, etc.; individual illumination, filters, partitions, etc., must be provided for specific personnel.

2) Acoustics: When several operators are in a compartment, special provisions may be needed to permit internal voice communication, while filtering out interfering and extraneous sounds.

3) Air Conditioning: When several persons are gathered into a compartment together with the equipments which they operate, the problems of air conditioning increase.

d. savings in space and equipment

When two or more men share a compartment, many savings are possible both in space and in equipment because the following can often be shared:

aisles, passageways, etc.

intercompartmental communication facilities

consoles, tables, workplaces, etc.

displays.

Problems can arise from one man's impeding the other or there being competition to use a certain facility. Thoughtful layout can greatly reduce such interference.

e. transient personnel

In some systems, there may be much traffic due to transient personnel concerned with messages, maintenance, and liaison. (See Section 1.3). Unless adequate provisions are made for such personnel, they are likely to hamper the operation of the system. Therefore:

1) Access space must be provided to (and adequate visual clearance for) important displays.

2) Room must be provided next to those personnel who receive and dispatch messages, instructions, etc.

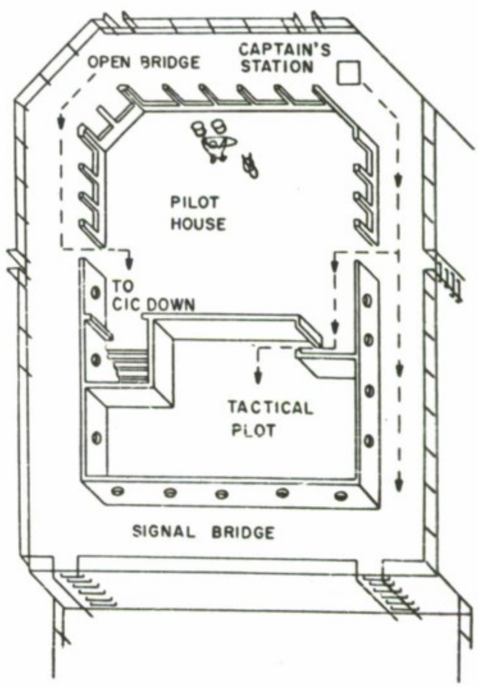
3) Aisle space and access aisles to "operating" positions must allow for continuous traffic.

1.1.3 Effects of Crew Mobility

The nature of the operator's job determines to a large extent whether he must be free to move around his operating station. Provision for such freedom affects the layout of the compartment.

In a field artillery unit, the amjunition bearer must carry live shells from the ready ammunition station to the loader. The gunner remains fixed at his gun sight station.

On Naval vessels, the commanding officer may move almost continuously around the bridge and pilot house and in and out of the CIC or tactical plot compartment. Others remain on the forward bridge to conduct various activities. Thus, the layout must provide for uncluttered access to various spaces to accommodate personnel who must move around to accomplish their jobs.



On jobs which require mobility, the operator will generally stand or use a sit-s arrangement. The effects of these positions on compartment layout will be pre sented here.

a. seated position

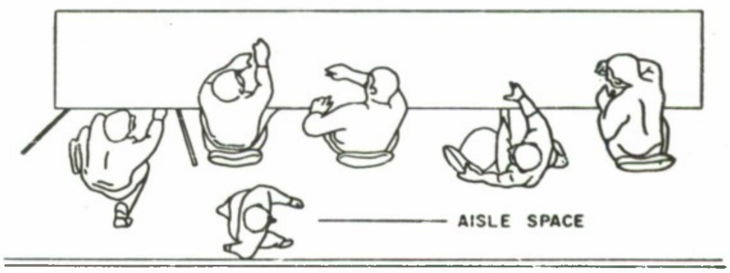
1) The control area is limited and movement from one position to another is hindered, unless there is a sit-stand layout.

2) Open space (not a part of the useful operating area) is generally require for access to the seat. (Rotary seats give good access with minimum space requirements.)

3) Space is required behind the seat for front-to-back seat adjustment.

4) If seats are in a row, additional space is required for access to the inside seats.

5) Where operators are seated in close proximity, space will be saved by running an aisle directly in back of the seats. This aisle space can be used jointly for general traffic, individual access to operating stations, seat adjustments, and maintenance purposes.



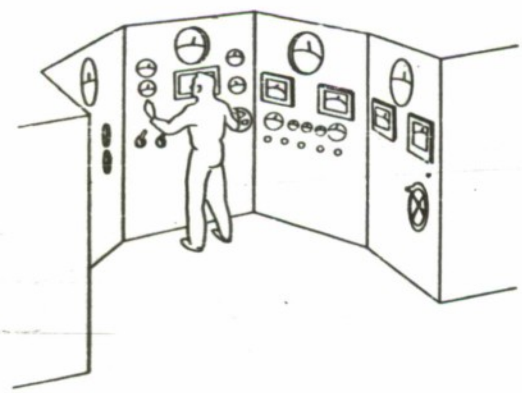
b. standing position

The standing position is characterized by the following space layout factors:

1) The standing operator requires less front-to-rear operating room. Foot control movements are generally vertical, and do not require forward leg extension, thus avoiding knee clearance problems. The standing operator requires more vertical room (than the seated operator) but except for isolated instances, as in aircraft, this room is usually available. Moreover, the standing operator requires no furniture.

2) The standing operator is more mobile, even when confined to a small operating position (which fails to take advantage of the operator's mobility) and can move out of another operator's way — either to allow him to pass or to allow him operating room.

3) Standing operators can be surrounded by instruments and controls.



4) Provided traffic is not too heavy, the operator can be stationed in a traffice space or aisle.

On a ship, controls and displays are mounted on the forward and aft sides of the bridge. The space between the bridge rail and pilot house is used both as a passageway and as an operating station.

Operators should not be forced to stand if the job does not specifically require it. Preferably, the designer should allow the operator to stand or sit at will, especially where work is prolonged and fairly continuous.

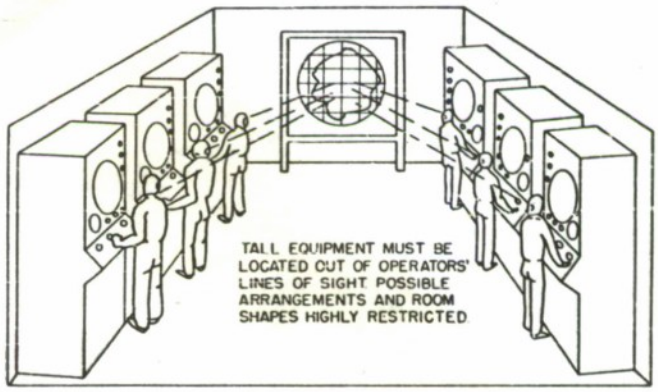
These factors permit the designer latitude in compartment layout as well as savings in total floor space (square feet) as compared with designs for seated crew members. Standing operators, however, find some pedal operations awkward and, in cases of pitching or moving platforms, they spend more time holding on than operating.

1.1.4 Effects of Equipment Size and Method of Operation

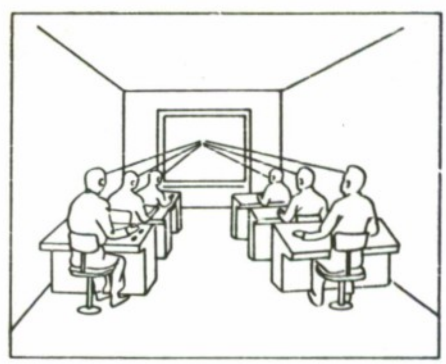
The gross dimensions of an equipment unit together with the clearances necessary for its operation should be considered as an integral space requirement. Additional equipment space requirements, such as clearance for maintenance, cables and ventilation, are considered in Section 2.4.

a. equipment size

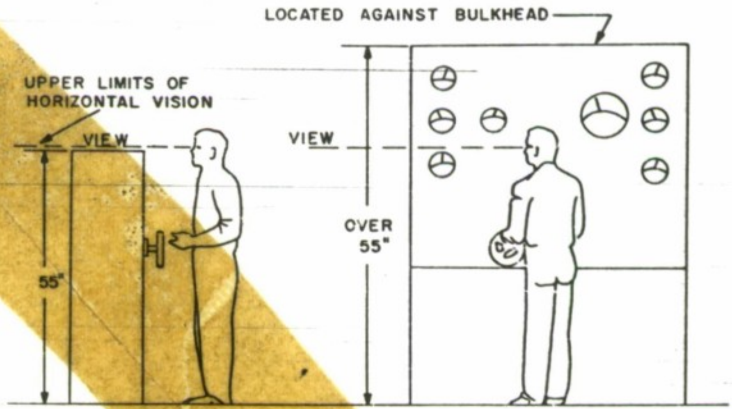
1) Height: Height of the equipment partly determines compartment dimensions, especially where clearances are needed for viewing the same display by more than one operator, and for verbal communication between operators.



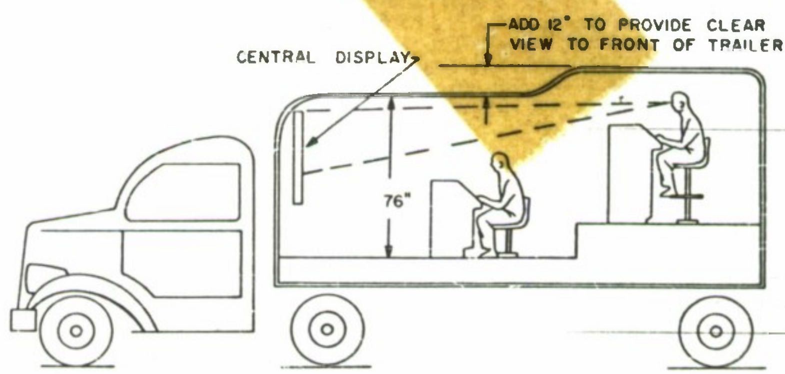
The short operator when standing has difficulty viewing over high equipment. It is not possible to state exactly the maximum permissible height of equipment over which something must be viewed. It will vary according to the location of the object to be viewed and the position of the operator (see Section 2.1). However, a height of 55 inches should



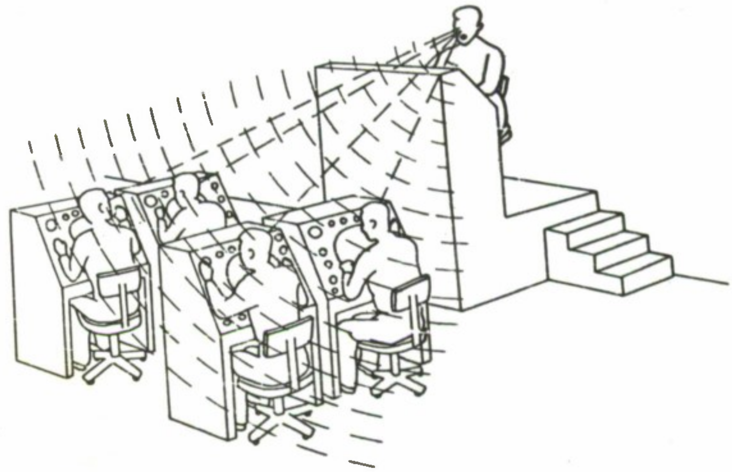
not be exceeded without ensuring that the extra height will not interfere with over-viewing. Therefore, equipment taller than this should be located against a wall or bulkhead or in an open space, so that it acts functionally as a wall.



Where operators attending tall units of equipment must view major displays, it may be necessary to provide additional compartment height for adequate visual clearances.



Communication by voice or visual signal between operators who are not seated side by side imposes similar requirements.



2) Overall Dimensions: The gross physical dimensions of the equipment, augmented by approximate requirements for operating areas, aisle space, etc., will yield an initial estimate of compartment size. In general, space can be saved when small rather than large units of equipment are used, because small units are versatile with respect to placement:

   a) They can be ideally located relative to the operator.

   b) They can be stacked, mounted overhead or on bulkheads.

   c) When used infrequently, they can be mounted in low-priority areas.

   d) They can be put through smaller hatches or doors.

   e) They can be carried or moved with less effort or mechanical assistance.

b. method of operating the equipment

Because space must be allowed for the personnel who will monitor and maintain the equipment, the volume required for operating the equipment can be added directly to that occupied by the unit itself. The design of the equipment will determine, within close limits, the method of operation and, consequently, the required operating room regardless of the placement of the equipment with respect to other units within the compartment.* Space requirements for standing versus seated operations have already been discussed in Sections 1.1.1 and 1.1.3.

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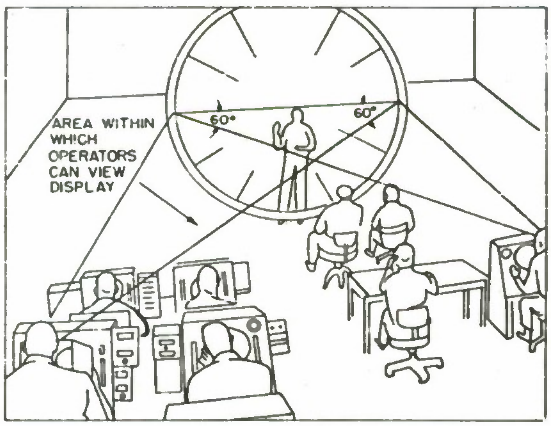
* Where scale models are used for designing compartment layout, equipment models should include known operating space requirements within their overall dimensions.

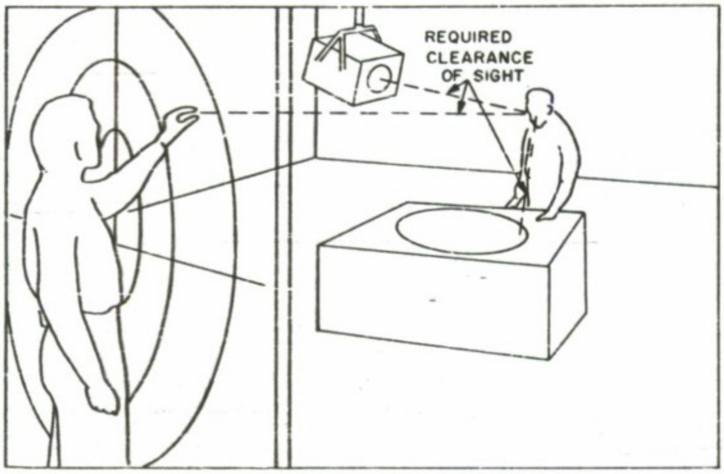
c. visual requirements

Clearances for adequate vision to major displays or to other personnel are discussed in Part 2 with respect to the placement of equipment. However, these requirements are also important factors in determining compartment size and shape:

1) Central Display: When a main display must be viewed by a number of personnel within a compartment, these personnel should be stationed so that: they get a direct view, and their line of sight to the display surface forms an angle between 60 and 90 degrees (never less than 45 degrees). If the majority of personnel must view the display, the area containing the display and personnel will be wedge shaped or an elongated rectangle, which will set at least one minimum dimension for the compartment.



2) Visual Linkages Between Personnel and Displays: In addition to the visual links with a main display, clear lines of sight may be necessary between personnel for communication purposes and to auxiliary displays, such as radar scopes. This may require an area of relatively clear vision in several directions, eliminating all equipment over about 55 inches in height from this area. The exact height of surrounding equipment will depend on a number of factors (see Section 2.1).



1.1.5 Effects of Communications

Communication facilities require special space planning both for the equipment itself and for operating room and access to the equipment. Provision for adequate communications imposes, among others, the following conditions on compartment layout:

a. communication within the compartment

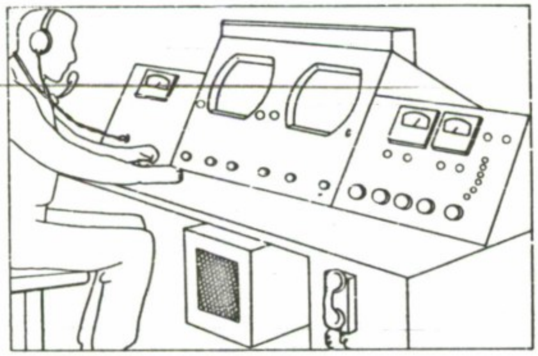
1) Auditory Methods: a) As with visual clearance, there should be clear space between personnel who will communicate directly by voice to insure adequate audibility (without shouting); also intelligibility of speech is greater when the listener can see the speaker.

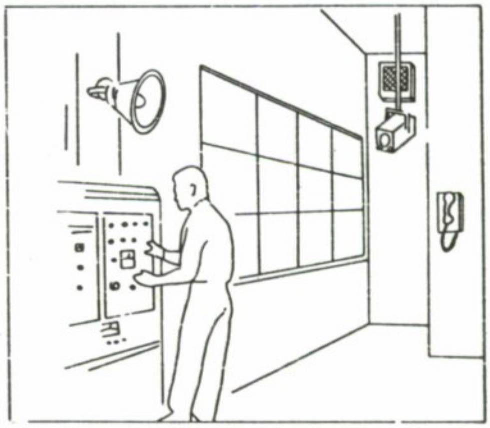
   b) All personnel requiring direct voice communication should be within normal voice range of the speaker. Acceptable voice range depends on the prevailing noise level, compartment size, etc.

2) Visual Methods: The distance between viewer and visual displays determines the required size and brightness of the display for effective visibility. In general, visual information should be arranged within 30 degrees of the viewer's normal line of sight. (See Baker and Grether (1) for detailed discussion.)

b. communication between compartments

1) Auditory Methods: a) Intercom units, handsets, voice tubes, plug-in headsets, etc.: Additional space may not be required where the communication unit can be located within normal reach of the operator (such as telephone or radio handsets). The individual units by themselves generally require little space and often can be fitted between larger units, mounted overhead or on bulkheads within convenient reach of the operator. The units should be placed outside normal passage and operating areas so that they do not cause, nor are subject to, accidents. Where communication equipment is shared (such as an intercom unit), the designer must provide operating room together with access space to the equipment.





b) Messengers, runners, etc.: Messengers require an access space to key personnel from main aisles which is large enough to prevent interference with the movements of operating personnel during the time in which messages are delivered or received for delivery.

c) Loudspeakers: The location of loudspeakers and their effect on room size and shape present problems in acoustical design and speech communication which are beyond the scope of this chapter. The layout problems include: (1) determining the desirable area covered by one speaker in competition with another, and (2) grouping of personnel which share information provided by the speaker.

2) Visual Methods: Intercompartmental communication by visual displays such as television receivers, display boards, is discussed in Part 2 and in Chapter II of this Guide (1).

1.2 GROUPING OF PERSONNEL

1.2.1 Formation of Groups

Men may be arranged in groups when there exists one or more of the following requirements:

a. More than one person must see the same unit of equipment or display; also, to avoid duplicate equipment.

b. Face-to-face communications are desirable (they are generally most effective); also, to reduce need for communication networks.

c. A single unit of equipment requires several operators.

d. Two or more units of equipment have to be operated in close proximity to each other (because of cross shafting, mechanical linkages, wave guides, etc.).

1.2.2 Location and Arrangement of Groups

a. requirements

The physical location and arrangement of groups should be planned to satisfy one or more of the following requirements:

1) Material, information, equipment, or personnel flows or is shared between two or more groups.

2) A single supervisor directs several groups.

3) Several supervisors coordinate the activities of their groups.

4) Several groups share certain facilities, e.g., laboratory, maintenance shop.

Plans for the physical location and arrangement of groups can be evaluated in terms of how well they meet these requirements by incorporating features like the following:

Locate closely related groups in a single building.

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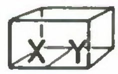

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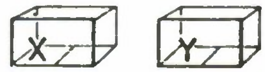

Locate closely related groups on a single floor.

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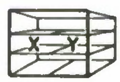

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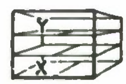

Juxtapose groups according to a plan of work flow (from A to D).

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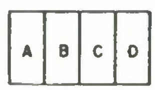

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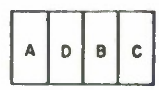

Integrate related activities (such as mechanical and nonmechanical, professional and nonprofessional, etc.) in accordance with actual requirements for contact (i.e., don't separate simply because their work is different).

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Though related activities should be close to each other, try to avoid disturbances (such as noise) by use of partitions.

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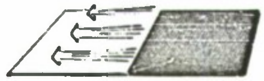

When noise is not a problem, separate related activities with space rather than partitions

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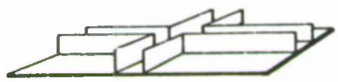

Provide privacy for supervisors.

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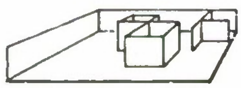

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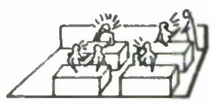

Locate supervisors so that they can readily contact their subordinates.

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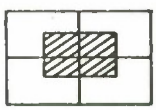

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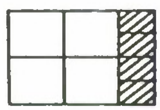

Integrate supervisory locations of closely related subgroups.

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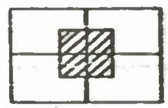

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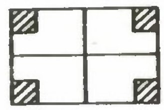

Provide face-to-face access for related groups.

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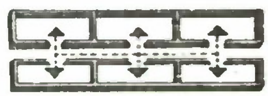

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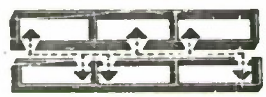

Integrate working areas which are closely related; do not separate arbitrarily by storage space, equipment, etc.

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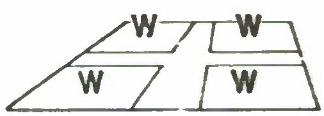

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Locate centrally a group which has many contacts with other groups.

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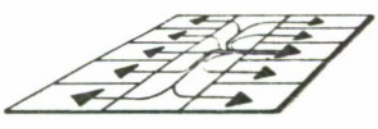

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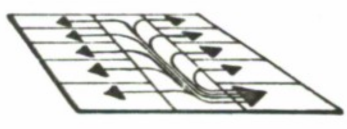

Shield quiet areas from noise of main traffic artery.

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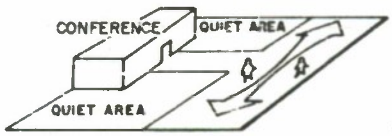

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b. examples of desirable group arrangements

This section illustrates some desirable group arrangements applicable to a variety of military situations, and may serve as a source of ideas for the designer of military man-machine systems. Each example is based upon actual cases, and its principal features are described.

~~The examples are as follows:~~

Electronics Equipment Development Laboratory

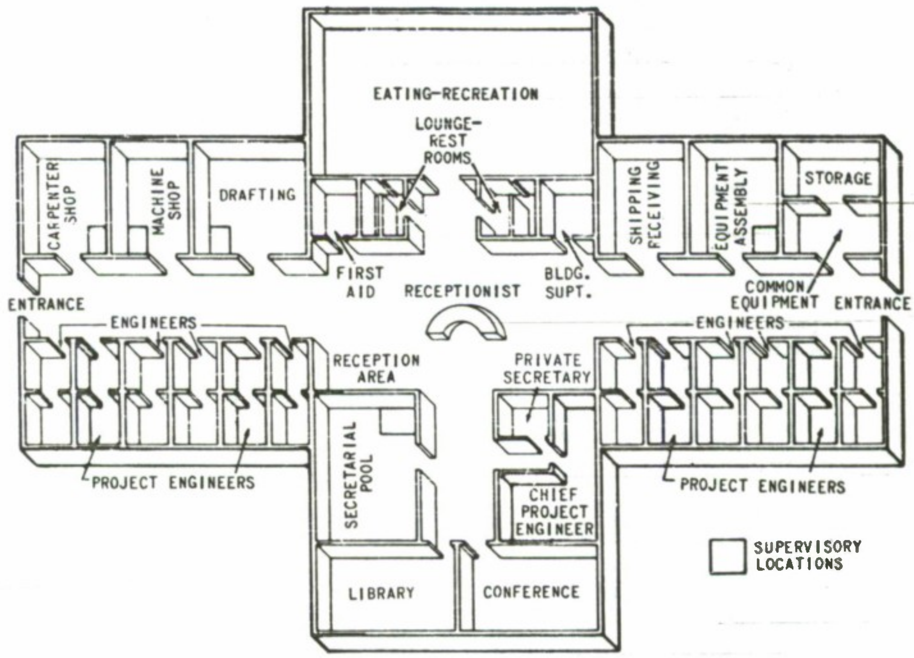
Combat Information Center (Land-Based)

Combat Information Center (Air-Based)

Portion of Submarine Control Area

Large Electronic Data Processing System

1) Electronics Equipment Development Laboratory*



Principal Features

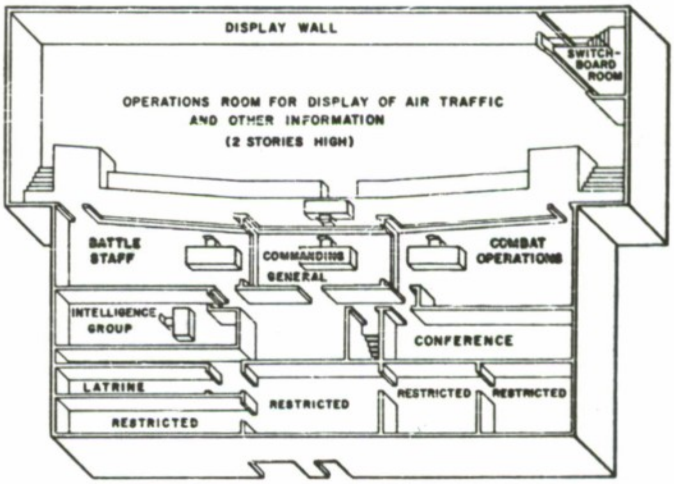
1. Central locations for people or areas having relatively equal contact with or use by most groups (chief project engineer, secretarial pool, first aid, building superintendent, lounge-rest rooms).
2. Relatively central locations for facilities utilized by high percentage of staff (eating-recreation, library, conference, shipping-receiving, drafting).
3. Interaction facilitated by face-to-face accesses to group areas, and location of lounge-rest rooms, eating-recreation areas, and entrances.
4. Supervisory locations compartmented and integrated with those of subordinates.
5. Development staff has privacy, experimentation and ship facilities, ease of access to superiors and each other (each engineer has combination office and experiment room).
6. Isolated locations minimized and counteracted by location of entrances.
7. Isolation of librarian counteracted by relatively central location which stimulates library use, and by proximity to secretarial pool.
8. Enlarged central area to accommodate traffic peaks.

*Not drawn to exact scale

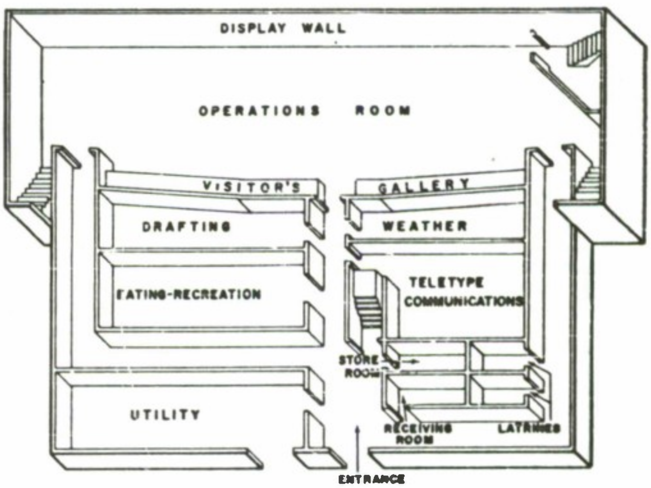
2) Combat Information Center (Land-Based)*

Principal Features

1. Central cluster of supervisory personnel permits inter-supervisor and supervisor-subordinate accessibility in accordance with contact need.
2. Location and transparent partitions permit personnel in areas of battle staff, commanding general, and combat operations to have both privacy and clear view of information displayed in operations room.
3. Conference room location facilitates accessibility by three primary user groups: battle staff, commanding general's staff, combat operations staff.
4. Location plus transparent partitions permit switchboard operator to search visually for personnel who are not at their stations.
5. Location of visitor's gallery permits both access ease and excellent viewing without disturbing center's activities.
6. Juxtaposition of drafting and weather groups to operations room facilitates delivery of information and materials from former, the suppliers, to latter, the users.
7. Relatively central and accessible eating-recreation area facilitates group interaction.



UPPER LEVEL



LOWER LEVEL

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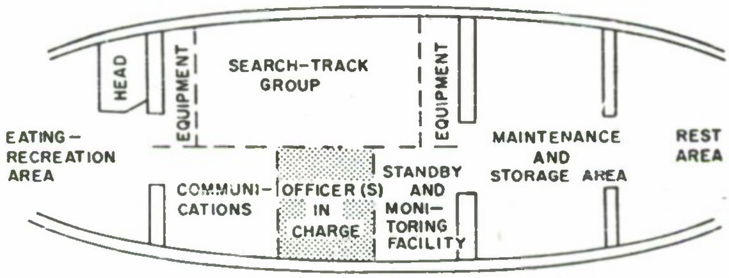
3) Combat Information Center (Air-Based)*



Principal Features

1. Central supervisory location makes it readily accessible to all other groups.

2. Location of communications area permits visual and verbal contact with officer in charge, e.g., can share displays.

3. Standby and monitoring facility is convenient to either the search-track or supervisory group.

4. Equipment required in work area is placed to one side so as not to break up the working groups.

5. Maintenance and storage area is readily accessible to working area.

6. Eating-recreation area and head are physically separated from, but convenient to, the work area.

7. Rest area is isolated from interference from both recreation and principal work areas.

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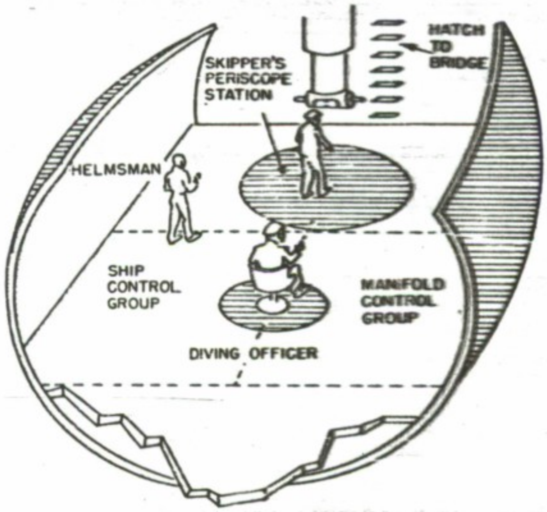
* Not drawn to exact scale

4) Portion of Submarine Control Area*



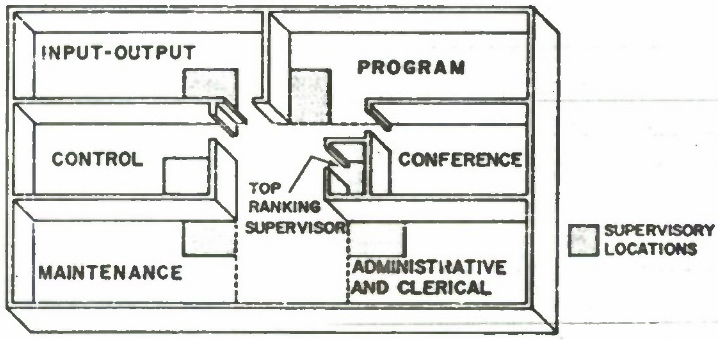
Principal Features

1. Central location of diving officer which, with aid of rotating seat, permits simultaneous supervision of two different groups.

2. Skipper's part-time location at periscope station facilitates ease of access from bridge, and direct verbal communication with diving officer and helmsman in accordance with work requirements.

*Not drawn to exact scale

5) Large Electronic Data Processing System*



Principal Features

1. Supervisory personnel ~~accessible to own groups as well~~ as each other.

2. Area juxtapositions facilitate flow of work and result in relatively short intergroup distances.

3. Administrative and clerical group approximately equidistant from other groups in accordance with work requirements.

4. Input-output and control group areas have noise-shielding structures to prevent disturbance of and from other groups.

5. Subcompartmentation provides privacy for supervisors.

6. Conference room for intra- and inter-system meetings located near personnel most likely to use it — top-ranking supervisor and program group.

*Not drawn to exact scale

1.2.3 Seating Arrangements

This section is concerned primarily with the advantages of various types of seating with respect to compartment layout. Anthropometric data for the design of seats and the relationship of seat design to the individual workplace are discussed in other chapters of this Guide.

a. individual seats

Individual adjustable seats are always preferable wherever the controls and displays can be so arranged as to fall within the operator's visual and manual working areas. Such seats enable a properly designed work station to be easily accessible to operators varying widely in height, reach, etc. Good seating design is generally low in cost compared with the total equipment cost per operator of almost any installation.

Table IV summarizes the relative merits of the standing and seated positions.

TABLE IV
Advantages and Disadvantages of Seated and Standing Operating Positions

Seated Position	Standing Position
Advantages	
Minimizes operator fatigue	Permits utilization of body weight in exerting forces
Increases stability and equilibrium of operator's responses	Increases mobility of operator
Permits maximum use of pedal controls	Permits large control motions
With adjustable seats, accommodates wide range in size of operators	Saves space required for seats
Provides body support when operator exerts horizontal fore-aft forces	Permits one operator to cover large work area
Disadvantages	
Limits size of control area	May lead to operator fatigue
Entails cost	Limits use of pedal controls
Requires space	
Sit-stand arrangements retain the advantages of standing position while deducing the fatigue inherent in having the operator stand all the time.	

As a general rule, individual seats should be provided whenever the operator is restricted to one operating position. These seats should be adjustable whenever the operator has to

1) Have his eyes at a critical height in order to see a specified display, e.g., an operator looking through a small aperture.

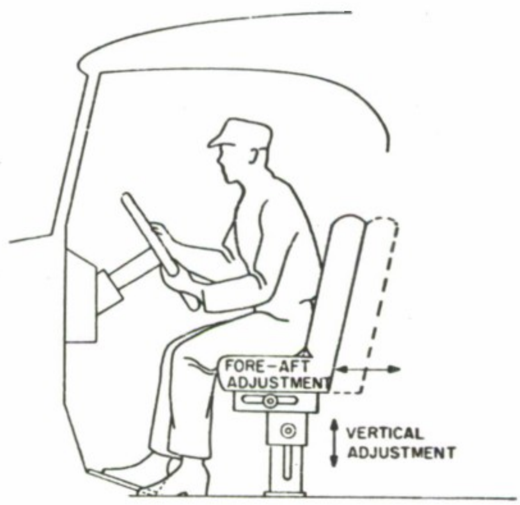
2) Operate critically important controls, either by hand or foot, e.g., an emergency footswitch.

In other cases it may be preferable to provide an adjustable seat, but it is not imperative. An adjustable seat is recommended whenever the operator

1) Uses hands and feet simultaneously.

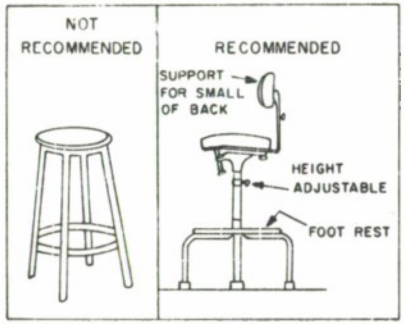
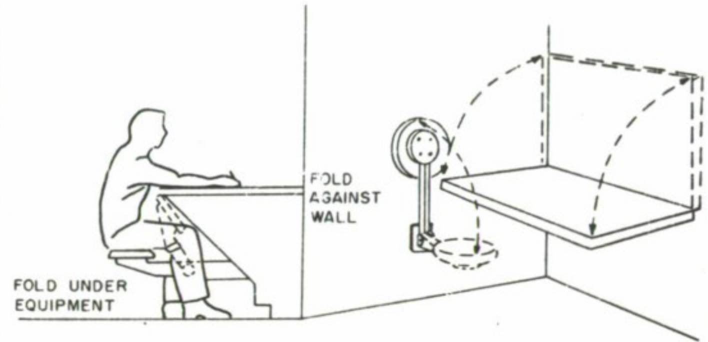
2) Uses pedal controls.

If a fixed seat is provided, seat height should be 18 inches above the floor, except where vertical space is limited and in specialized applications, e.g., some aircraft cockpits. When any form of seating is provided in a moving vehicle, it must be firmly fixed to the structure of the vehicle; for the driver of a vehicle both fore and aft and vertical adjustments are recommended.



Advantages and disadvantages of the draftsman-type stool and fold-out stool are listed in Table V.

TABLE V
Advantages and Disadvantages of Draftsman-Type and Fold-Out Stools

Draftsman-Type Stool	Fold-Out Stool
	
Advantages	
Height adjustable Easy to use Easy to move in and out of position Can be provided with back rest Easy to move in and out of position Requires little room	Provides solid, rigid seat Is adaptable to almost any work layout Can be stowed in space provided for operator's legs Can be used with pedal controls
Disadvantages	
Too space consuming, difficult to adapt to equipment where leg room is not available Not secure against vehicle movement or vibration Not a good support where other than low control forces are used (high center of gravity)	Unsuitable for pedal controls No standard foot support Generally no back rest available Requires special support on stanchion or bulkhead

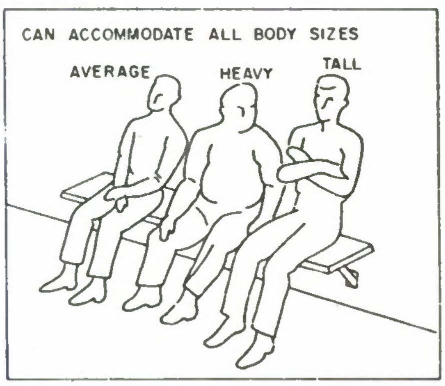
b. benches

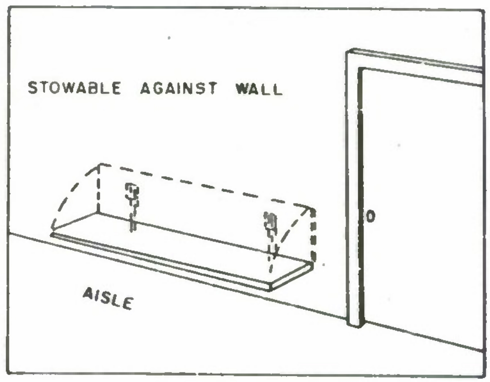
A bench is considered here to be a seat designed to accommodate two or more persons; it may be fixed or movable, and it may have a back rest. If mounted on a wall, the latter may serve as the back rest. The "park" bench has little practical use in military or industrial situations.

Benches may be used as temporary seating for transient personnel for short periods (preferably not over a half hour), but never in place of an individual seat for personnel operating equipment. This rule holds true both for permanent installations and for mobile vehicles (Army personnel carriers, troop carrier aircraft). In the latter instance, where personnel are passive and do not interfere with active operators, the time limit depends only on individual comfort considerations. The advantages and disadvantages of benches are presented in Table VI.

TABLE VI
Principal Advantages and Disadvantages of a Bench Compared with Individual Seating

Advantages	Disadvantages
Accommodates all bodily types and sizes without adjustment	Adjacent operators likely to interfere with each other
Inexpensive to construct	Because of lack of adjustment, can meet optimum requirements of very few layout problems
Economical of space—adaptable to many different arrangements	Cannot be controlled by one operator, i.e., movement of the bench requires simultaneous cooperation of all persons seated on it
Stowable—fits well against walls bulkheads	
When hinge-mounted, can be used in aisle spaces	
Acceptable for use as temporary shelving or other storage facilities	
Requires little front-to-back room	
Can accommodate maximum number of personnel within a given space	





Benches are of particular value where:

1) Personnel using them are passive, nonoperative.

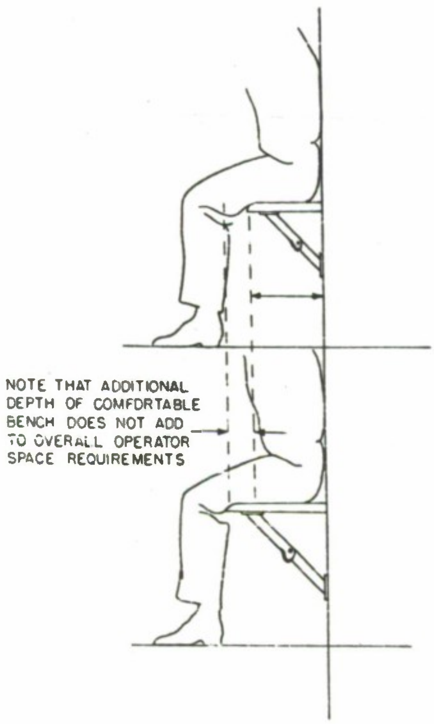
2) Time required to use the bench is relatively short.

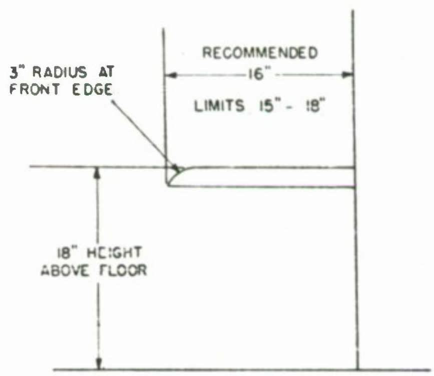
3) Personnel must take up minimum lateral space.

Bench seats--particularly when they are stowable in some form-- should have recommended seat dimensions. The use of narrow (in depth) benches in order to save space is a fallacy. The user requires the same amount of space (buttock-knee dimension) regardless of bench depth.

Depth: 15 inches to 18 inches recommended.

Height: 18 inches (must be close enough to ground so that even short-legged man can rest his feet on the floor.)





1.2.4 Classrooms

The design of classrooms has been thoroughly studied by school architects, and detailed recommendations are readily available (17,18,24). Therefore, discussion of this subject has been omitted from this chapter.

1.2.5 Conference Rooms

Conference or briefing rooms are frequently useful in military and business installations. Conference rooms as described in this section include compartments which will seat as many as 20 to 30 persons; rooms which hold 30 to 100 persons may be called classrooms; compartments which hold 100 or more persons are defined as auditoriums and are discussed in Section 1.2.6.

Ideally, a conference grouping in which all present are to participate actively should probably seat not over 8 to 10 persons. With larger numbers, it tends to become difficult for the group to function as a unit. Seating in a conference room should be adaptable to a table-type arrangement. This is a more satisfactory method of encouraging discussion than the speaker-audience relation found in classrooms and auditoriums. The table gives a large work surface for material which may be examined at close range by all participants rather than by being projected on a screen.

A properly equipped conference room should have one or more optical projectors (for slides and moving pictures), a screen, a blackboard, and a display board. Use may also be found for voice recording, amplification, and playback facilities.

a. presentation of information

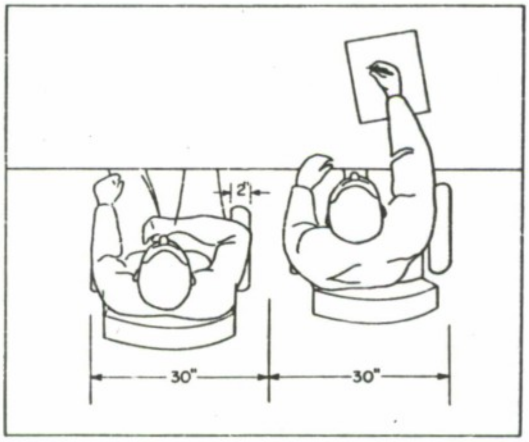
1) Viewing angles: The viewing angle between line of sight and information on a screen or wall should be at least 60 degrees, if possible, and never less than 45 degrees; for moving pictures, the larger value should be used.

2) Visibility: Recommendations on the design of visual details to ensure adequate legibility and visibility are discussed in detail by Baker and Grether (1).

3) Auditory Information: Although a microphone and speaker should be available for such circumstances as an unusually large number of personnel in the conference room, or for a lecturer who will make a long briefing, the room size and acoustical design should make voice amplification unnecessary. The table seating arrangement will aid in this respect since each person partially faces the other persons in the room.

b. seating arrangements

1) Distance Between Personnel: Thirty inches per person is recommended as the minimum lateral allowance for personnel seated at a table. This permits use of an armchair with 2-inch-wide armrests, with both of the user's arms resting on the arm supports.

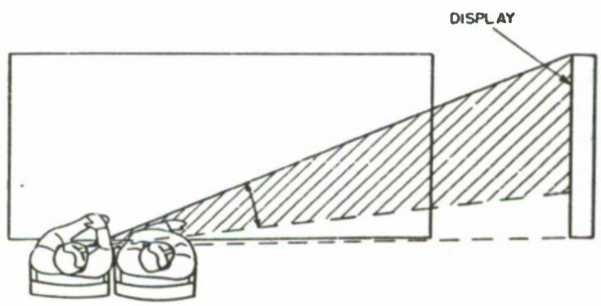


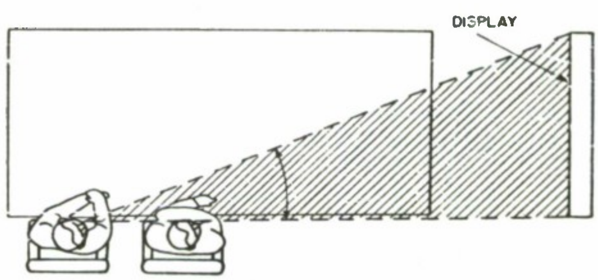
2) Visual Clearance: When persons are seated at a table in a row roughly perpendicular to a visual presentation, the lateral distance between personnel becomes critical. Visual clearance depends on:

a) Width of display in relation to width of table.

b) Lateral distance between individuals.

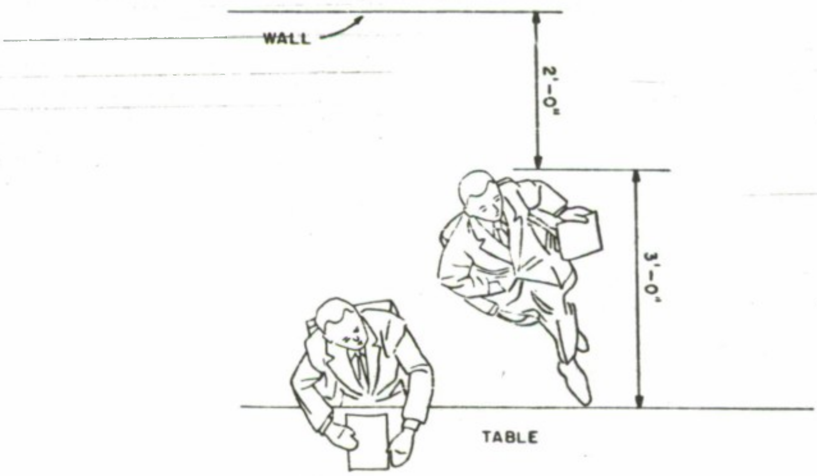
The persons nearest the displays can shift backwards to get out of the way, although this may interfere with note-taking.



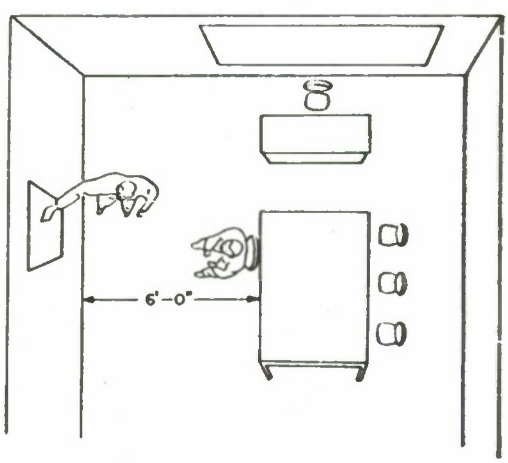


c. aisles and entrances

1) In a conference room, aisle space is usually no problem because the general layout assures easy access to the seats and other points in the room. A minimum clearance of 4 feet between the table edge and the nearest wall will provide a 2-foot aisle along the wall when people are seated at the table. An additional clearance of 1 foot will retain 2 feet of aisle space and allow freedom of movement for the seated persons.



With 6 feet or more clearance between table and side wall, this wall can be used for displays which can be seen by all persons at the table.

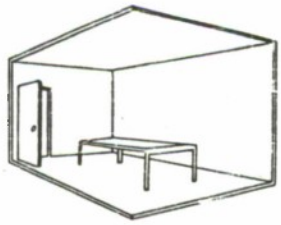


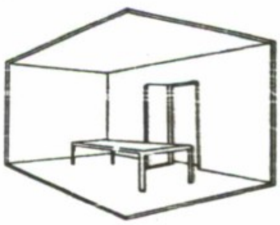
2) Doorways or other entrances should be located in a corner of the compartment. This location will:

a) Maximize wall space for large displays.

b) Minimize clearances needed for entrance space.

(In cramped areas, a folding or sliding door should be considered.)





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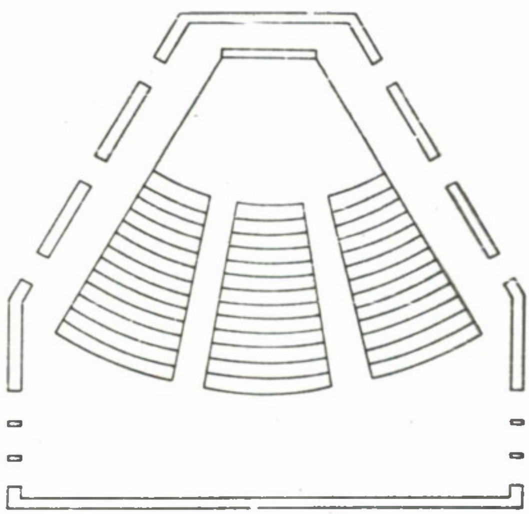
1.2.6 Auditoriums

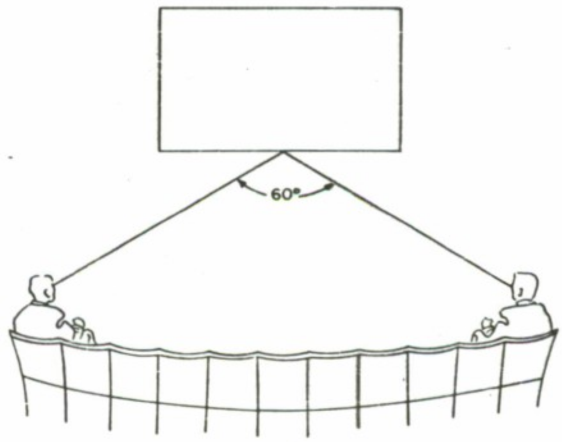
The design of an auditorium generally involves a series of compromises to make the space convenient for most, but not all, of the audience.

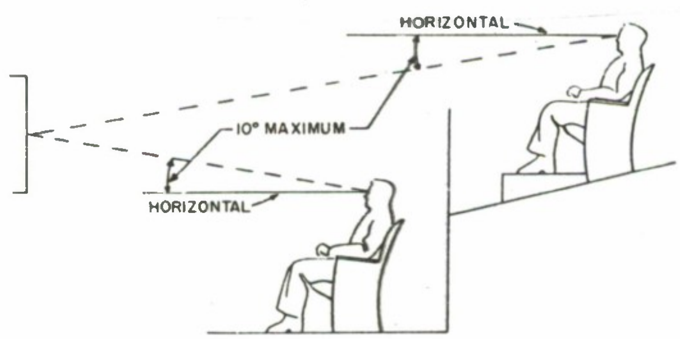
a. visual factors

For purposes of viewing a display, such as a chart or movie screen, the ideal shape of an auditorium is a fan or a truncated wedge.

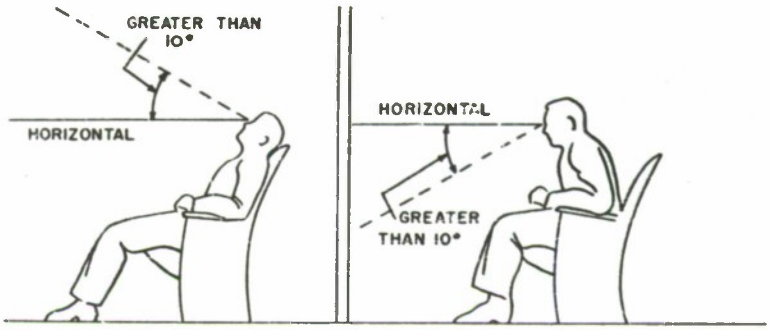


Acceptable angles of viewing are not less than 60 degrees in the horizontal plane and 10 degrees from the horizontal, either up or down, in the vertical plane.

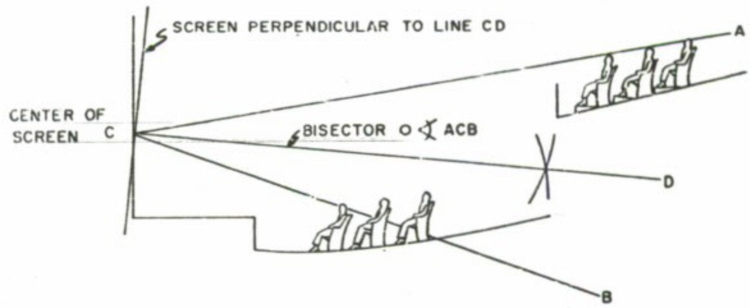




If the vertical angle exceeds 10 degrees either up or down, viewers will either slump or lean forward in their seats.



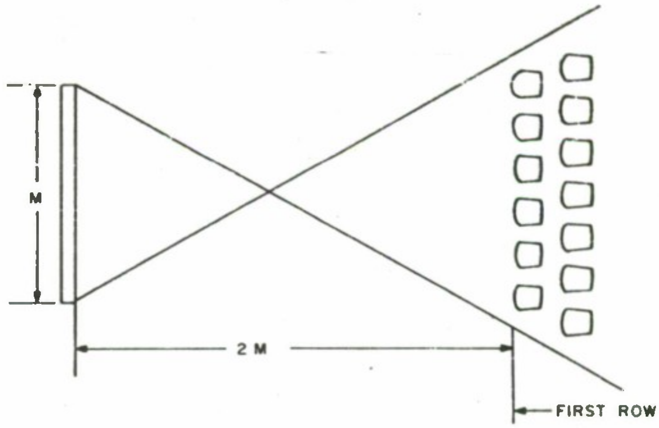
Ideally, the angle of the screen should be at 90 degrees for all observers. In practice this cannot be realized; an effective compromise is shown in the accompanying illustration.



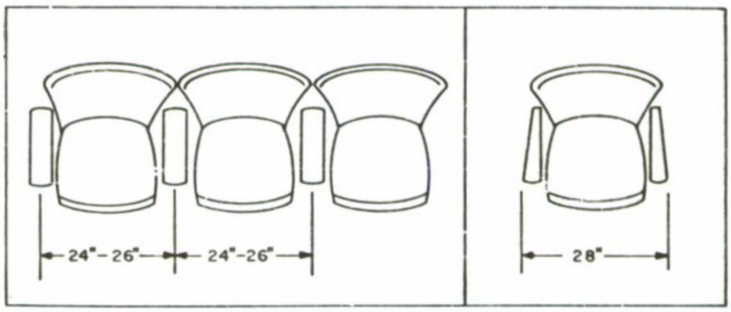
For a detailed discussion of theater design, see the series of articles by Schlanger (13).

b. seating factors

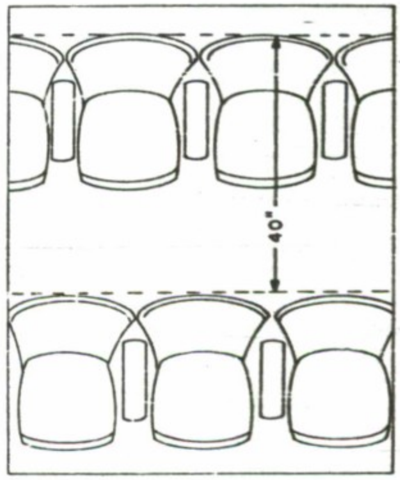
1) Distance from Display: A practical rule of thumb is that no seats shou be closer than double the maximum dimensions of the visual display.



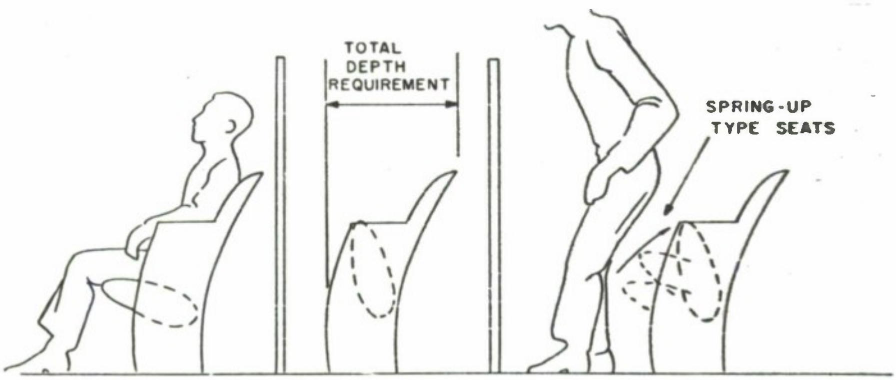
2) Spacing Between Seats: Where the seats are divided by a single armre 24 to 26 inches are recommended. A 28-inch width per seat is recom- mended where two armrests are provided for each individual seat.



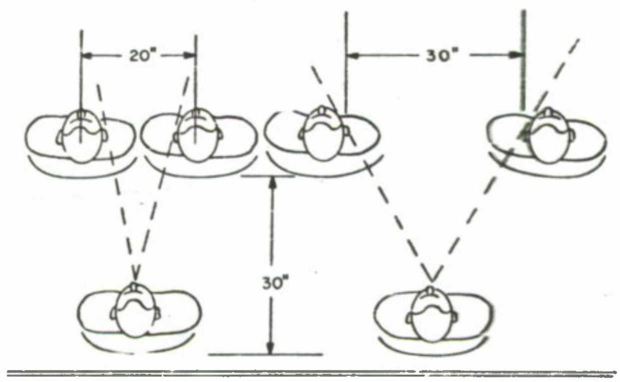
Forty inches is the recommended separation between seats in adjacent rows, depending on the desired auditorium seating capacity and available space.

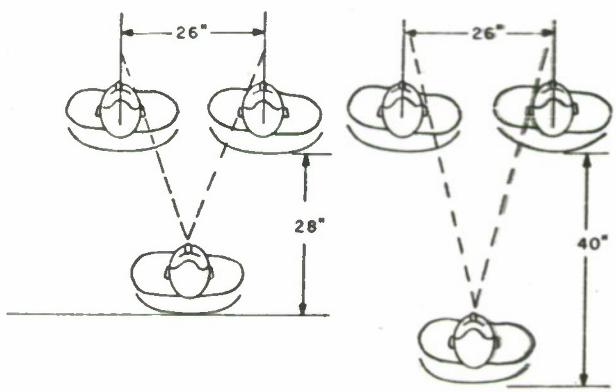


3) Seat Type: The seats should have a narrow silhouette and be of the "spring up" type.



4) <u>Staggered Seat Arrangement (See also Section 2.1.3)</u>: A staggered seating arrangement is essential to permit minimum vision over the shoulders of persons in front of the viewer. The design should permit a short man (sitting eye height of 29.4 inches plus seat pan height) to see the bottom of the display over the shoulders of a tall man in front of him (sitting shoulder height of 27 inches* plus seat pan height). The horizontal angle of the field of view is a function of both the lateral separation between seats, and the separation between rows.





For further details for optimizing the horizontal field of view, see Ramsey and Sleeper (12).

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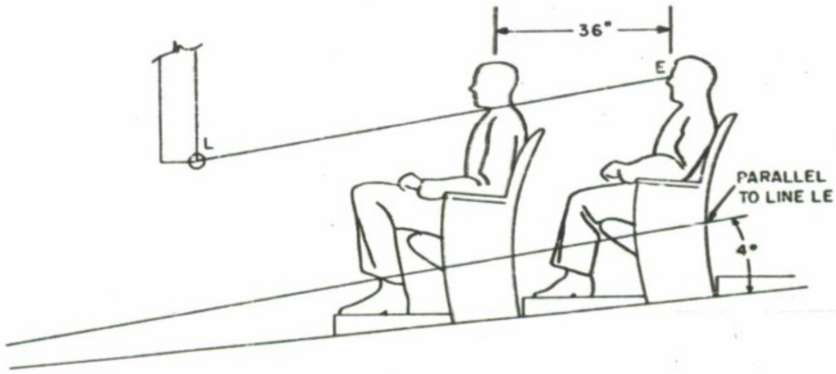
*Height of shoulder near neck, not to be confused with height of shoulder point (acromion).

c. elevation

On a level floor, the eye height of the short man (29.4 inches above seat level) is about 2-1/2 inches above the shoulder height of the tall man. On the main floor of an auditorium, there is no difficulty in seeing the bottom of the screen (not true for children). When the bottom of the screen or other viewed object is below the level of the eye, the angle between E (eye of viewer), L (lower part of display), and the floor should be not less than 4 degrees. For the short man to see over the head of any person two rows in front would require a minimum angle of 9 degrees.



d. aisle space, exits

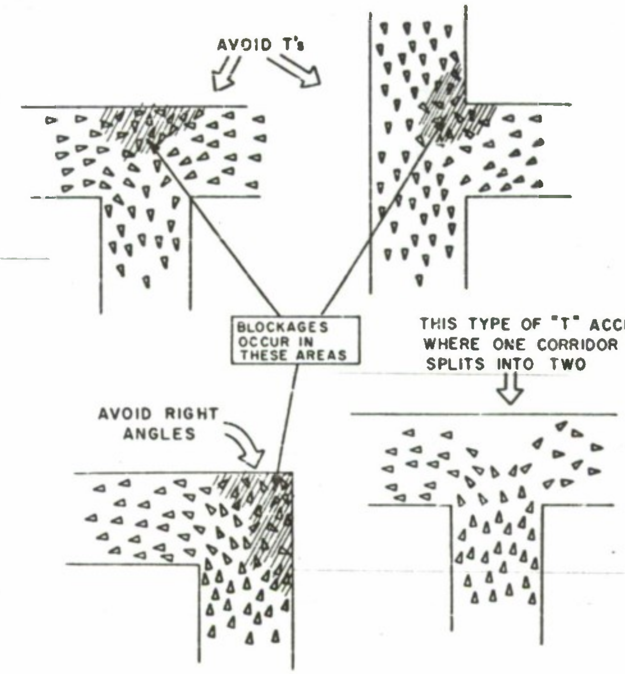
This subject is considered separately in Section 1.3. A few recommendations are included here which relate to auditoriums and other installations subject to very heavy traffic flow.

Emergency exits are mandatory and are specified by existing building codes. The following general recommendations will help assure optimum safety and speed under emergency exit conditions:

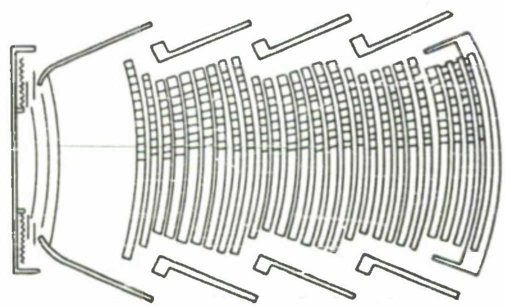
1) Allow adequate clearance (40 inches) between rows, and use automatic swing-up seats.

2) Use main exit aisles along sides of auditorium, and place exit doors along these sides. (Safety codes demand that doors will push open away from the inside.)

3) Avoid T's and especially right-angle turns where persons can get jammed into a corner.



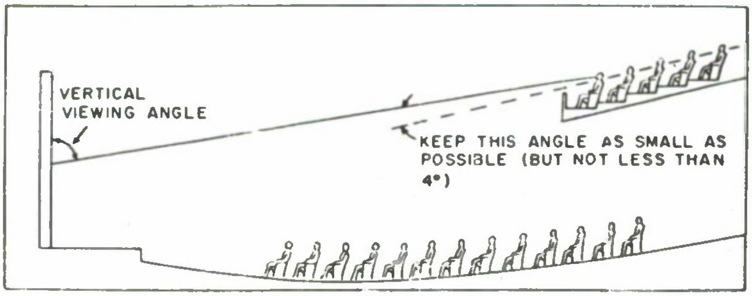
If building codes permit, the following design is recommended. For larger auditoriums, a center aisle may be necessary.



Multiple aisles are desirable in one respect: By having a narrow block of seats, the number of seated persons who must be passed in a row is minimized when a person is going to or leaving his seat.

e. balconies

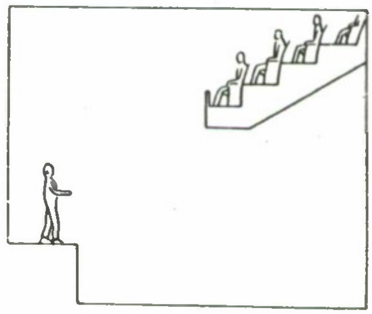
The design of balconies is largely dependent on what is being viewed. When the presentation is on a large central screen (as in a combat information center), desirable viewer's distance from the screen is a function of image size and sound qualities. In order to keep the vertical viewing angle close to 90 degrees, the floor pitch should remain fairly small.



When an auditorium is to be used predominantly for small presentations (especially when "live," such as a lecturer, panel of speakers, cast of actors), it is important to minimize the distance from the audience to the stage (13). This can be accomplished by:

1) Bringing the front of the balcony close to the stage.

2) Increasing the pitch of the balcony.



1.3 TRAFFIC FLOW WITHIN AND BETWEEN COMPARTMENTS

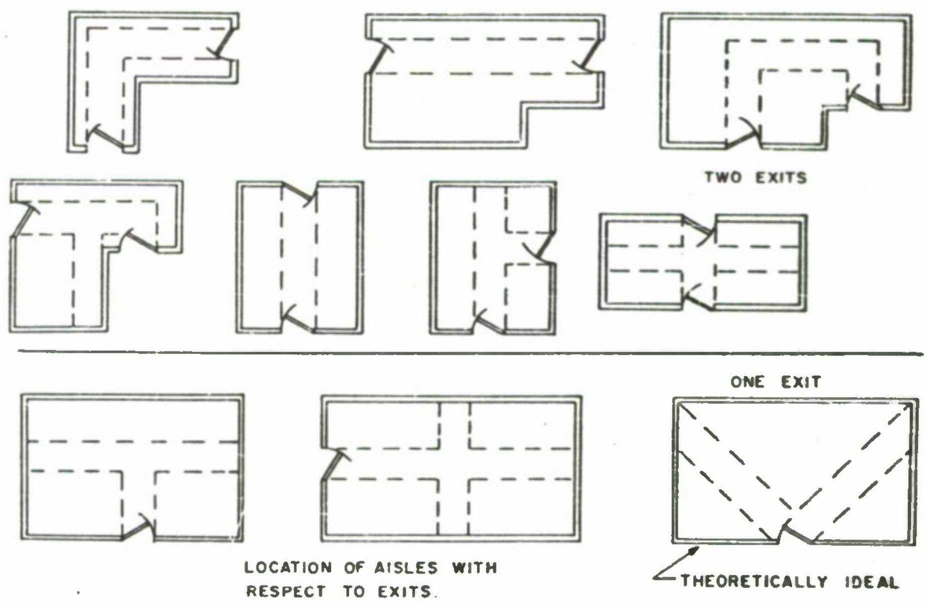
Although access spaces, passageways, and stairs must generally be provided, they are not, strictly speaking, part of the working area. Therefore, the placement of working groups and the arrangement of equipment and operators must be given first priority. If a choice is required, adequate operating room can usually be justified, at the expense of space for traffic.

An architect designs space for traffic in terms of the type, amount, and weight of the traffic, with consideration for frequency of use, routing, speed, etc. Discussion of such factors may be found in standard sources (21,22,25); the present discussion is limited to the human factors aspects of such design.

1.3.1 Aisles and Corridors

Aisles are spaces designed to provide for the passage of men and materials within a compartment; corridors, between compartments, i.e., between areas separated by a wall or partition. In hangers or depots, where large areas are enclosed to form a single compartment, no distinction need be made between aisles and corridors.

An aisle is advisable when there will be an appreciable amount of traffic within a compartment during normal operations. When there is slight traffic, such as an orderly change of personnel at the end of a shift, it can be made through whatever path is available (assuming there is no special requirement for purposes of safety,etc.). In any case, it is clear that arrangement of operators, displays, and equipment, and establishment of clear lines of sight, etc., must be given prime consideration. The following figure suggests the recommended location of aisles with respect to exits.



LOCATION OF AISLES WITH RESPECT TO EXITS.

The following guide rules will be found useful in the design of aisles and corridors:

a. Keep them straight: put in as few corners as possible; avoid blind corners.

b. Locate paths for minimum distances; flow charts, diagrams, movement analyses, etc., will tell where most traffic will be.

c. Mark traffic guides (aisle limits, arrows, etc.) on floor, wall, or ceiling.

d. Keep intersections at 90 degrees; this minimizes lost floor space.

e. Keep aisles clear: do not allow equipment or columns to protrude into any aisle.

f. Avoid locating an aisle against a blank wall, since this permits access from only one side.

g. Avoid one-way traffic in aisles (because it will not be followed); it is possible, but not desirable, for corridors.

Table VII gives recommended widths for aisles and corridors. An aisle can be narrower than a corridor because it carries less traffic and because it is usually convenient for one person to wait or stand aside while another passes; in corridors, there should be free passage for all personnel.

TABLE VII
Recommended Widths for Aisles and Corridors (10,12,14,16)

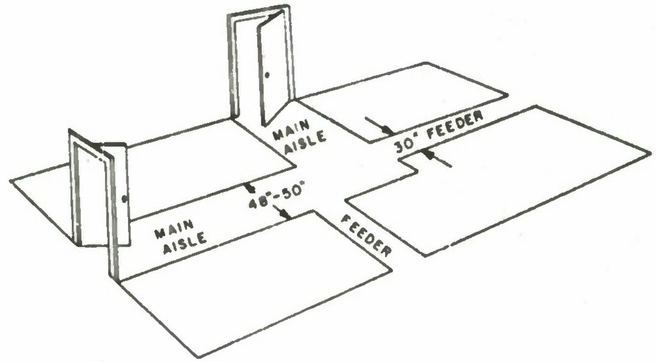
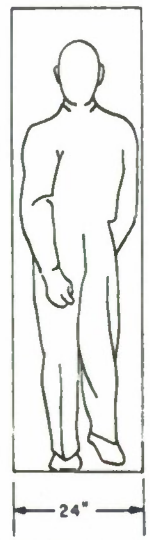
Traffic	Minimum	Recommended	
Feeder aisles	20 inches	30 inches	
Main aisles	40 inches	48 to 50 inches	
1 person	20 inches	24 inches	

TABLE VII (Cont'd)

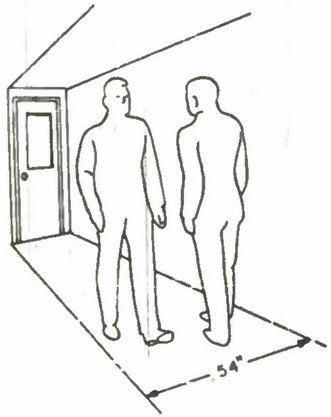
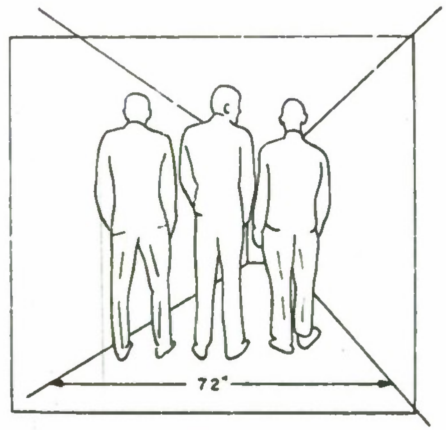
Traffic	Minimum	Recommended	
2 persons passing	44 inches	54 inches	
3 persons abreast	60 inches	72 inches	

TABLE VII (Cont'd)

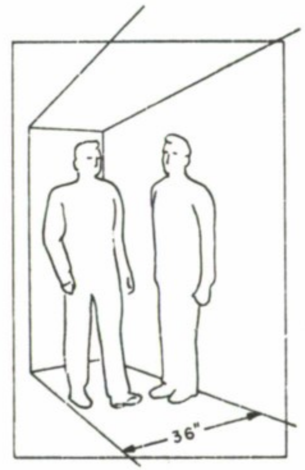
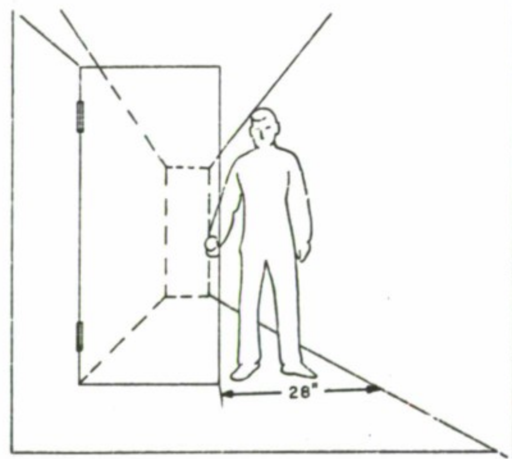
Traffic	Minimum	Recommended	
1 person passing, 1 standing against wall	30 inches	36 inches	
1 door opening into corridor	Door width plus 24 inches	Door width plus 28 inches	

TABLE VII (Cont'd)

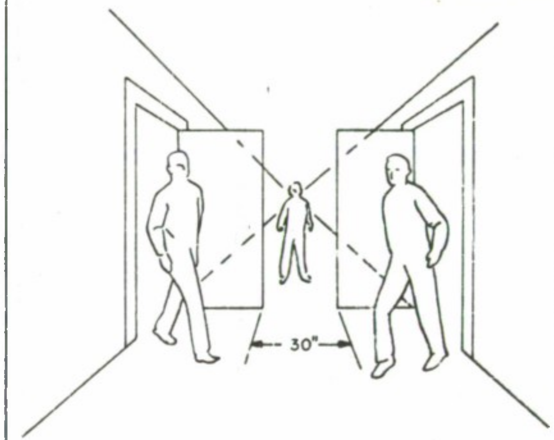
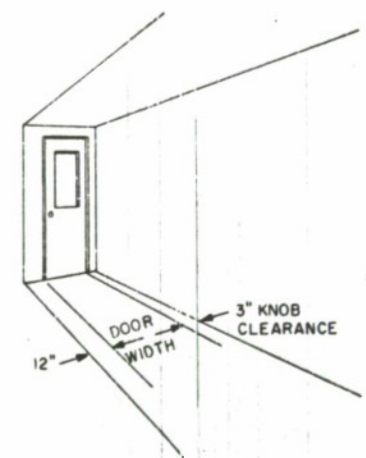
Traffic	Minimum	Recommended	
2 doors opposite opening into corridor	Twice door width plus 24 inches	Twice door width plus 30 inches	
Door at end	Door width plus 4 inches	Door width plus 15 inches	

TABLE VII (Cont'd)

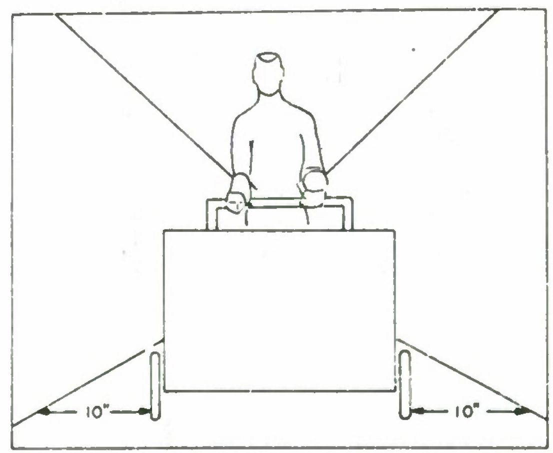
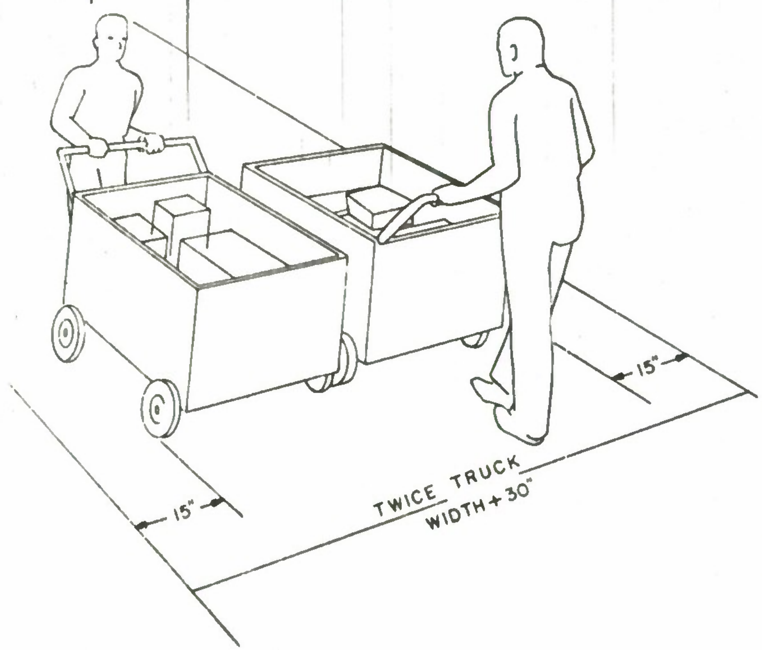
Traffic	Minimum	Recommended	
2-wheel hand truck, no passing or turning with load	30 inches		
Stock truck (plus clearance for trucker)	Truck width plus 20 inches		

TABLE VII (Cont'd)

Traffic	Minimum	Recommended
Stock truck (where other truckers and workers must pass)	Twice truck width plus 30 inches	
Hand-operated fork truck, pallet transport, etc.	Determined by load dimensions	
Powered fork trucks	Determined by load dimensions	

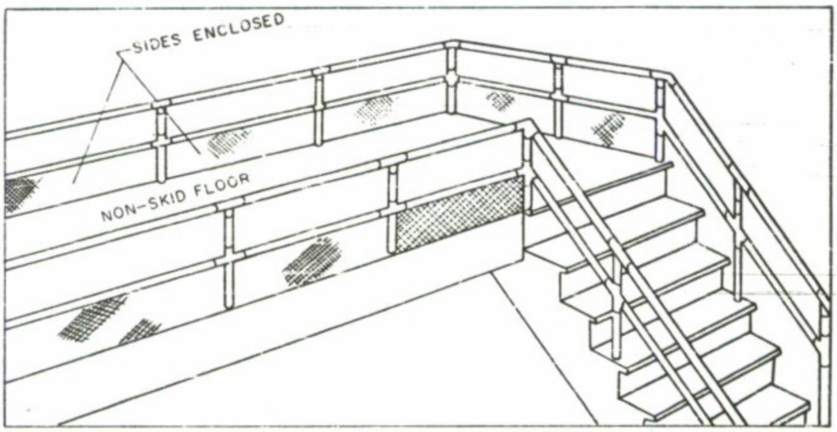


1.3.2 Special Traffic Handling Spaces

This section describes several special facilities for handling traffic, such as catwalks and tunnels, which can be recommended only where space or environmental conditions preclude normal aisles or corridors.

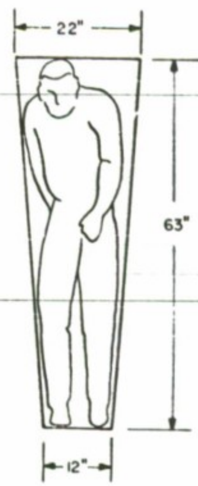
a. catwalks

The floor of a catwalk should have a nonskid surface. The stairway to the catwalk should be at right angles to the catwalk. Upper and lower guard rails should be provided and the sides should be enclosed with wire mesh (or other screening) to prevent the feet from stepping off the floor.

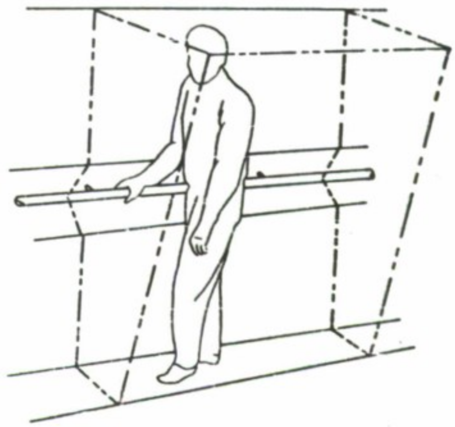


b. enclosed walkways (see Woodson (16))

Fully enclosed walkways (or tunnels) which allow the user to walk erect may be shaped roughly to the human contour to minimize space and weight requirements. Lateral measurements shown in the figure (hip and shoulder heights) may have to be increased for personnel wearing or carrying bulky equipment.

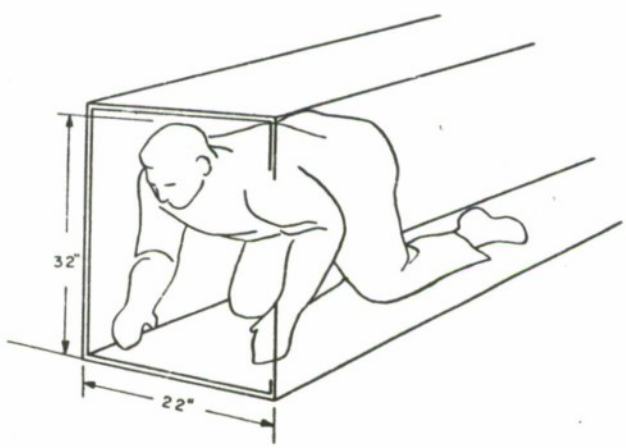


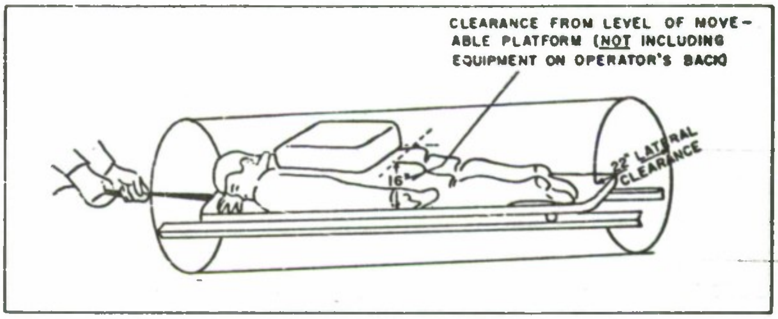
If the walkway is in a moving vehicle, a handrail should be provided to support personnel.

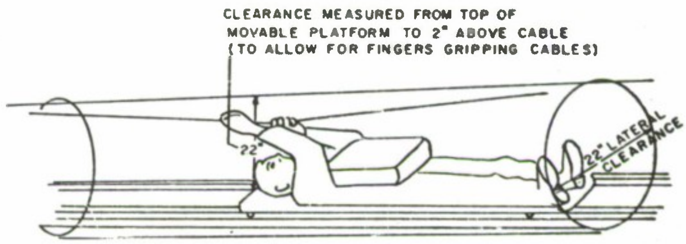


c. tubes, crawl spaces, tunnels or other passageways

Sometimes the only feasible type of passageway is one in which the user must stoop, creep, crawl, or slide. Dimensions for such spaces are provided in the accompanying figures; the data are based on the 95th percentile man. Any allowance required for equipment or heavy clothing should be added to these data.





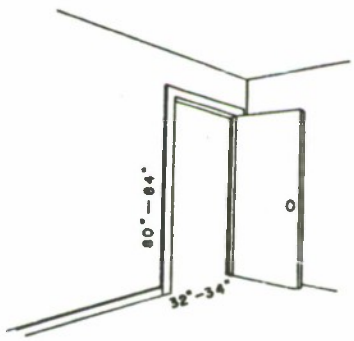


1.3.3 Openings Between Enclosed Spaces

Doors, arches, and hatches are openings which connect one compartment directly to another, to a corridor, or to the outside.

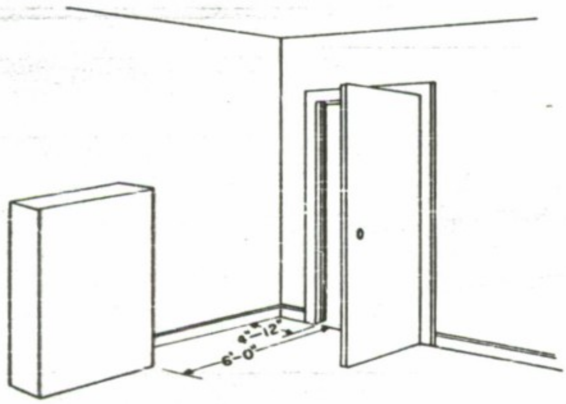
a. doors

1) Hinged Doors: The dimensions shown in this figure are adequate for access to and from a compartment for one person at a time; larger dimensions may be required for moving bulky equipment.



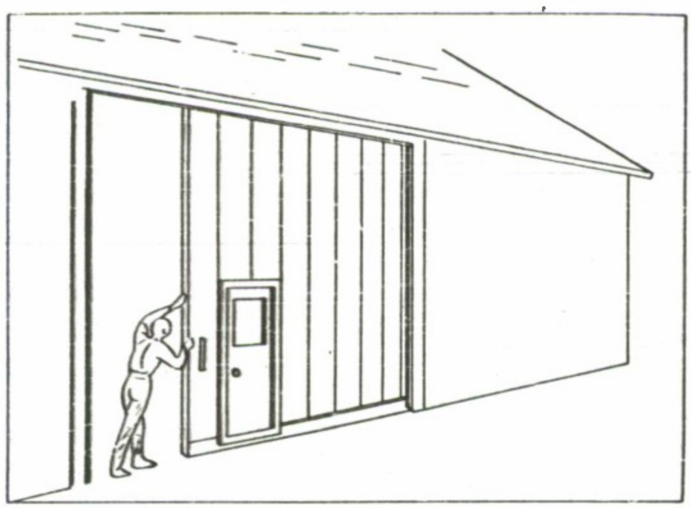
Saddles in doorways are not recommended except where weather protection or special ventilation control is required.

Clearance of at least 4 inches and preferably 12 inches on the "knob" side of the door is recommended, extending out 6 feet from the doorway.

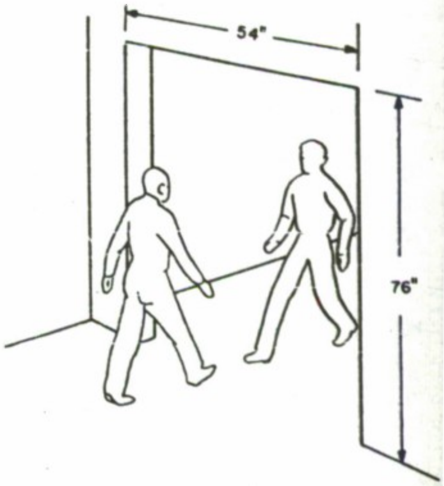


2) Sliding Doors (Vertical or Horizontal): Sliding doors are useful for cramped spaces. However, they are easily jammed when subject to blast, collision, etc., and therefore should never be installed as the sole means of exit.

Where large vehicles or pieces of equipment have to be moved in and out of compartments, a sliding door is recommended. A separate hinged door in the sliding door is recommended.



b. arches

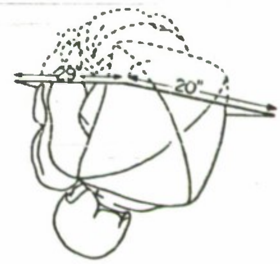


The dimensions given in the accompanying figure apply to any unobstructed opening between compartments. If space and structural strength permit, an archway should be wide enough to allow two men to pass through simultaneously. Saddles or other projections from the floor at the bottom of the archway should be avoided.

c. hatches

Hatches include armored, watertight, or otherwise bulky doors which, due to small size, heavy weight, and structural requirements, cannot be considered as ordinary (wooden) doors.

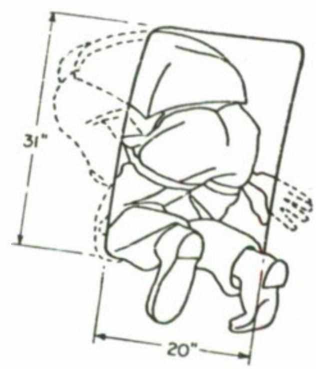
1) Escape Hatches: The proper dimensions for escape hatches will depend upon the compartment to be escaped from, the equipment and clothing worn by the man, and the environment he is entering. References are available for escape hatch sizes for special purposes, e.g., ejection from aircraft (15,23):



Top hatches: 22-inch diameter circle or 22-inch square

Belly hatches: 20 x 29 inch rectangle

Side hatches: 20 inches wide x 31 inches high.



The types here do not apply to high-speed aircraft for which there are special ejection requirements.

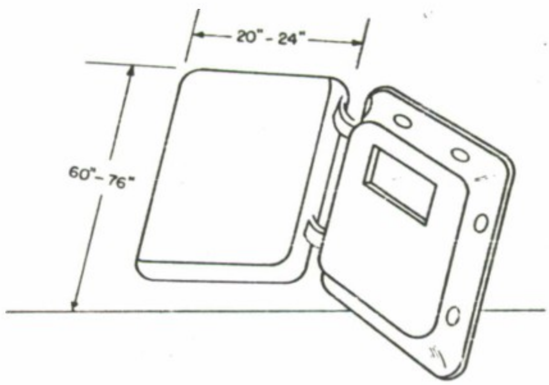
In general, it is advisable to study the particular conditions of escape before deciding upon the size of the hatches.

Side hatches should be flush with the floor if structural considerations permit. Release must be possible by a single motion of the hand or foot and, when a handle is used, the force required should not exceed 30 pounds.

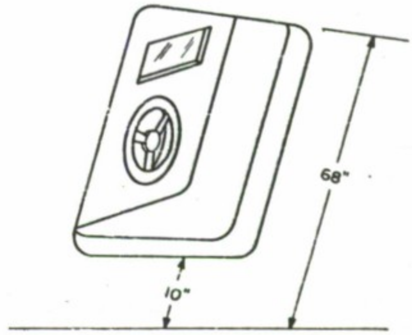
2) Watertight or Armored Hatches: Heavy metal hatches must be as small as possible to reduce weight and to preserve the structural strength of the bulkhead or deck in which they are mounted.

a) <u>Bulkhead-mounted Hatches</u>

Minimum width:	20 inches
Recommended width:	24 inches
Minimum height above deck:	60 inches
Recommended height:	any addition to minimum height up to 76 inches (which permits the 95th percentile man to walk through erect) is helpful.



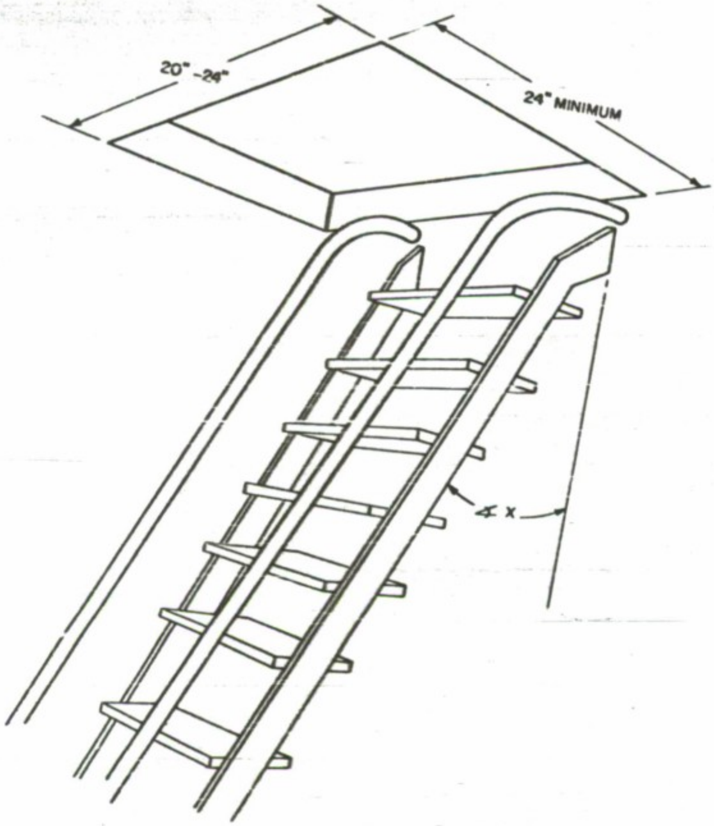
If men must go through the hatch bearing heavy loads, it produces less muscular strain to step over a high sill than to stoop excessively. In this case, 68 inches minimum is recommended for the top of the hatch. Height of sill above floor can be 10 inches. In no case should a sill come to crotch height (5th percentile, 30.4 inches).



Avoid placing corners, protrusions, and sharp edges near hatch openings. For regular travel through hatches, design for the range of the population that will use the hatch and not just for the average man.

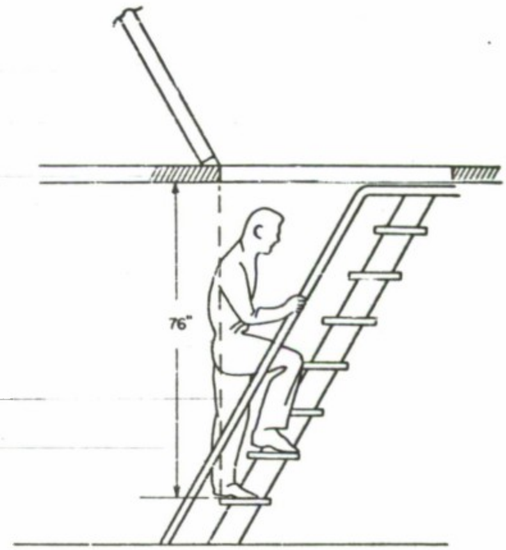
b) Deck-Mounted (Horizontal) Hatches

Minimum width:	20 inches
Recommended width:	24 inches
Depth:	depends on the angle of ladder leading up to the hatch; i.e., the shallower the angle, the greater must be the depth of the hatch.
Recommended depth:	Depth (inches) $\simeq$ 30 secant $\measuredangle$ X.


20"-24"
24" MINIMUM
∠ X

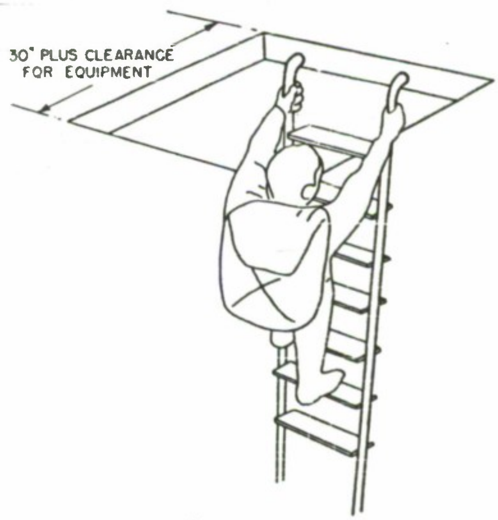
Vertical distance between lower front edge of hatch and ladder tread immediately below this point:

Minimum:	68 inches
Recommended:	76 inches



With vertical ladders:

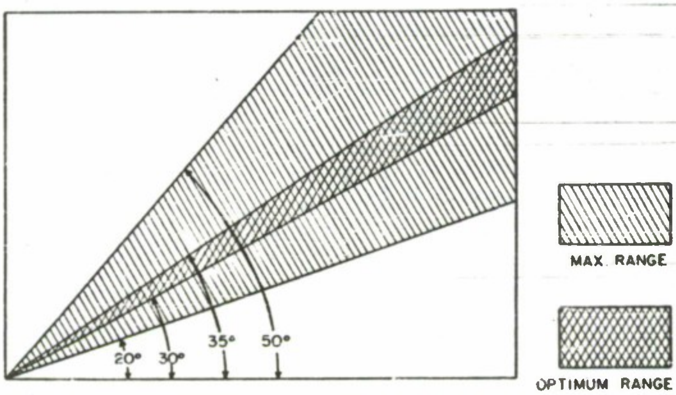
Minimum depth of opening:	24 inches
Recommended depth:	30 inches plus clearance for any additional equipment a man may carry on his back.



1.3.4 Structures for Handling Traffic Between Levels: Stairs, Ladders, Ramps, Escalators, Elevators

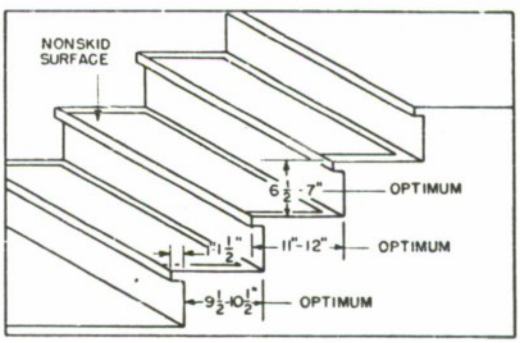
a. stairs

Stairs should rise from the horizontal at an angle of between 20 and 50 degrees, with optimum range between 30 and 35 degrees.



Ratio of riser height to tread depth will depend on the stair angle (6,12). Recommended optimum depth is 9-1/2 to 10-1/2 inches plus 1 to 1-1/2 inches nosing. This gives sufficient depth so that, in decending the stairs, the ball of the foot does not extend beyond the front edge of the tread, while the heel comfortably clears the nosing of the step above.

Recommended height of riser:	minimum 5 inches to maximum 8 inches, optimum 6-1/2 to 7 inches.
Recommended depth of nosing:	minimum 1 inch, maximum 1-1/2 inch.



Tread should be provided with a nonskid surface.

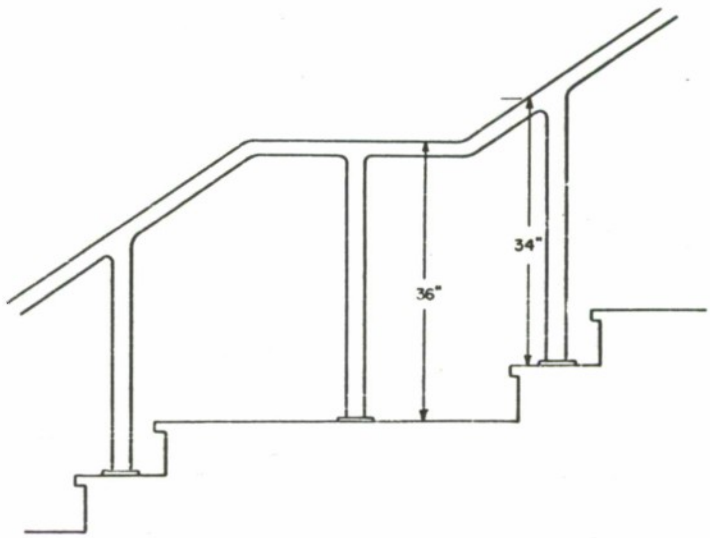
Avoid long stair flights. Where space permits, landings are recommended every 10 to 12 treads.

Stairs should have a handrail on at least one side.

Recommended height of handrail:

Between top of handrail and tread: 34 inches

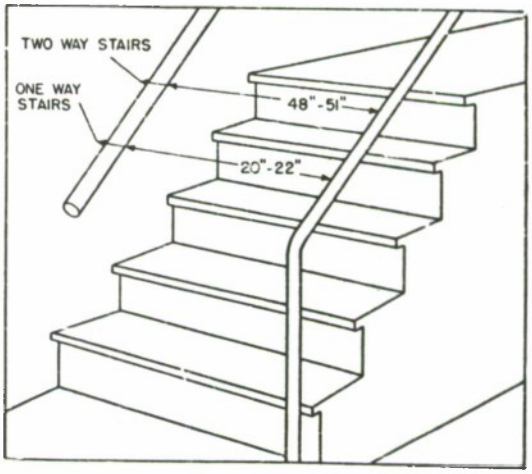
Between top of handrail and landing: 36 inches



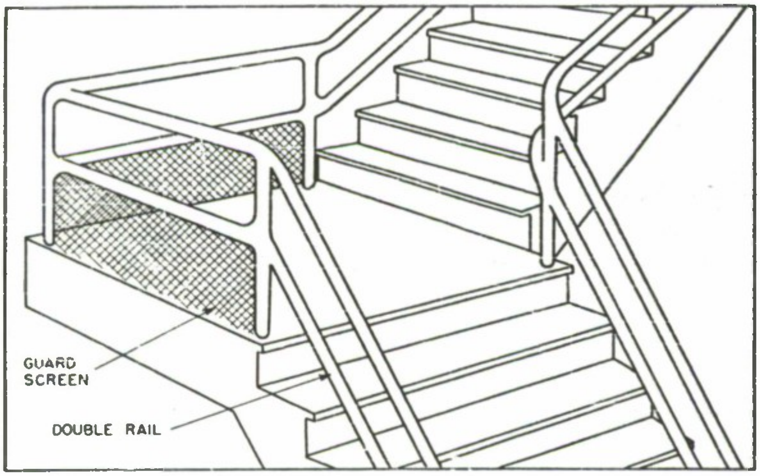
Width of stairs (between handrails or between wall and handrail):

One-way: 20 inches minimum
22 inches recommended

Two-way: 48 inches minimum
51 inches recommended



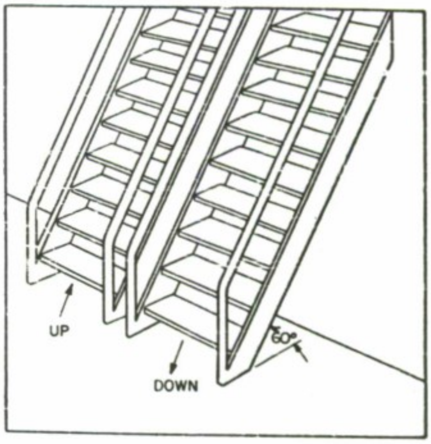
For open stairways and landings, guard rails should be provided halfway between handrails and treads. In addition, screen guards should be provided for landings which do not butt against walls.

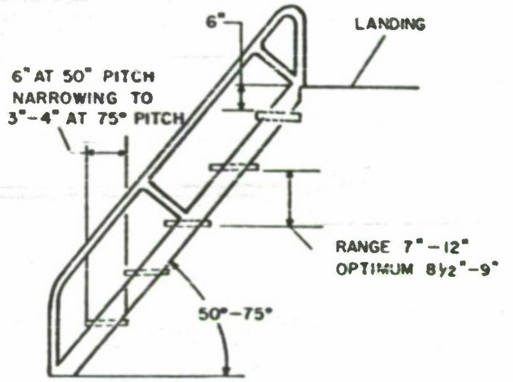


b. ladders

Ladders should be used where the desired rise from the horizontal is at an angle of 50 degrees and more, or where stairways are not practicable. For ease of discussion, ladders are divided into two types: step ladders and vertical ladders.

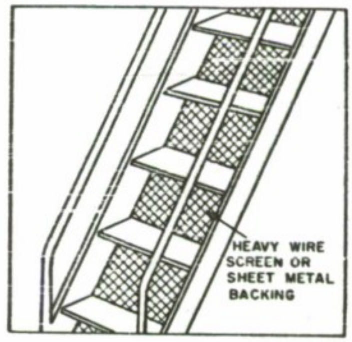
1) Step Ladders: Step ladders use flat horizontal steps or treads, and handrails. The most familiar example is the ship's ladder which usually rises at an angle of 60 degrees. Clearance should be sufficient for one person only. If simultaneous two-way traffic is desired, separate UP and DOWN ladders should be provided. If these are located side by side, a double center handrail should be provided.





Recommended depth:	6 inches for 50-degree rise narrowing to 3 to 4 inches for 75 degree rise.
Recommended rise between treads:	Maximum 12 inches Minimum 7 inches Optimum 8-1/2 to 9 inches
Recommended distance between top tread and landing:	6 inches

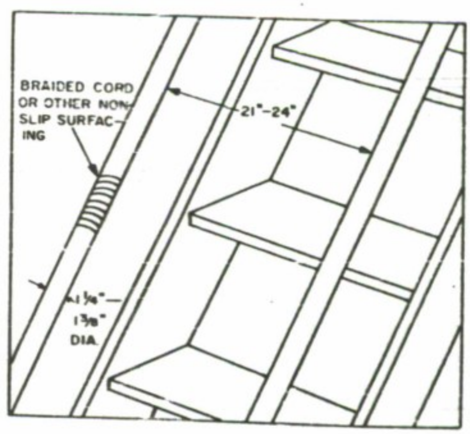
Treads should be open (without risers) and be provided with nonskid surfacing. Metal screening should be fastened to the underside to prevent the foot from slipping through. Where ladders are located one above the other, metal sheeting may be used to protect the head from bumping against the treads of the ladder above.



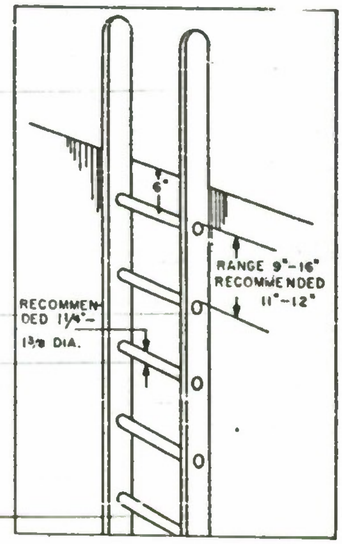
Handrails should be provided on both sides of the ladder, and should be covered with braided cord or other nonslip surfacing.

Diameter: 1-1/4 to 1-3/8 inches

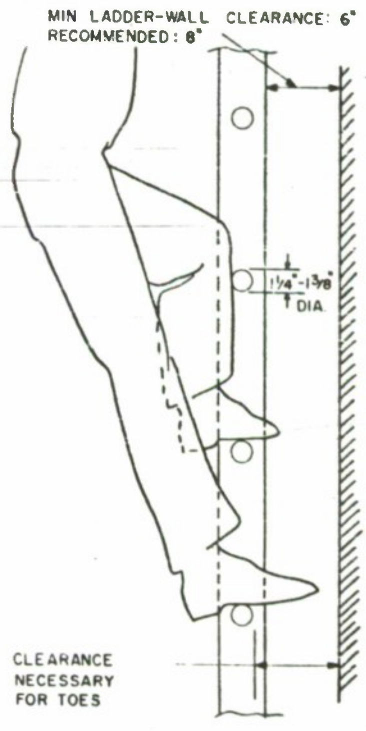
Distance between handrails: 21 to 24 inches



2) Vertical Ladders: Rungs are used to provide hand grips and foot supports for inclines between 75 and 90 degrees.



Rise between treads:	9 to 16 inches
Recommended:	11 to 12 inches
Rise between landing and top rung:	6 inches



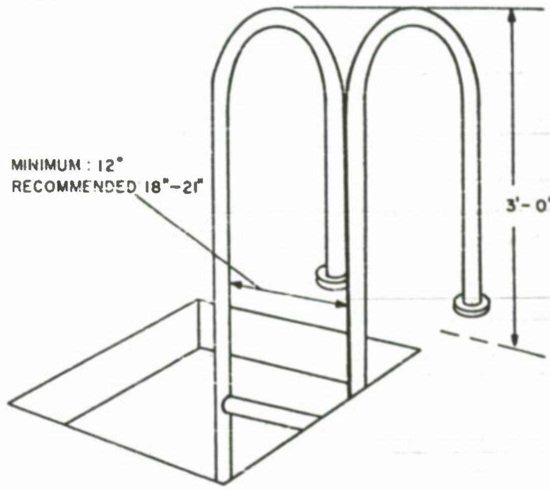
Rungs must be round to provide a good hand grip. The rungs must be surfaced with a nonskid material and the surface maintained.

Recommended rung diameter:	1-1/4 to 1-3/8 inches
Minimum distance between rungs and supporting wall:	6 inches
Recommended:	8 inches

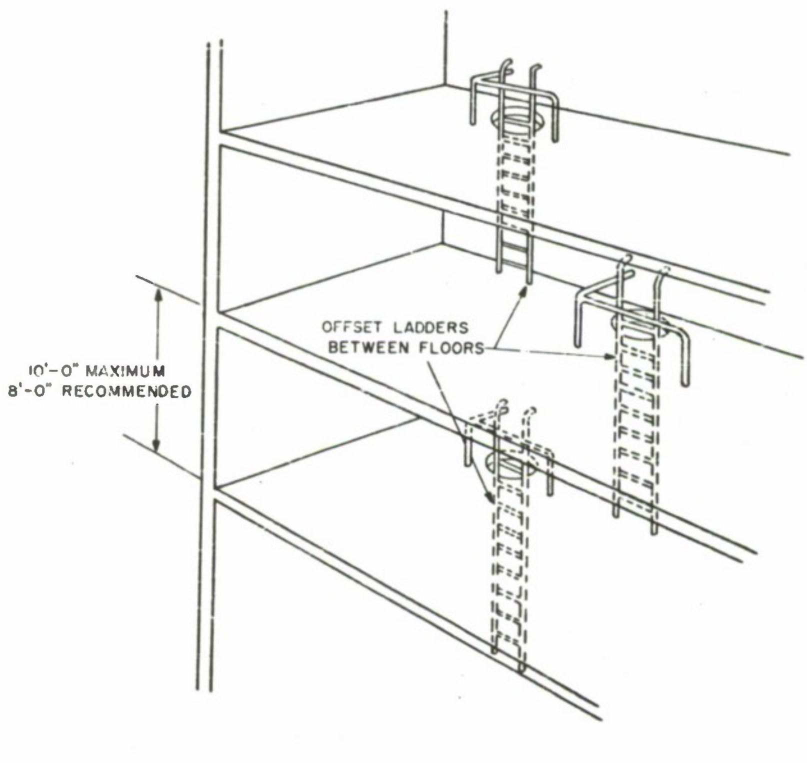
Ladder strings (vertical supports to which rungs are fastened) should extend above the top floor level to a height of 3 feet if possible.

Horizontal distance between strings (ladder width):

Minimum:	12 inches
Recommended:	18 to 21 inches
Length of vertical ladder:	10 feet maximum between landings
Recommended:	8 feet



If ladders are used between several floors, they should be offset every floor. Guard rails should be provided at the top entrance to ladders.



c. ramps

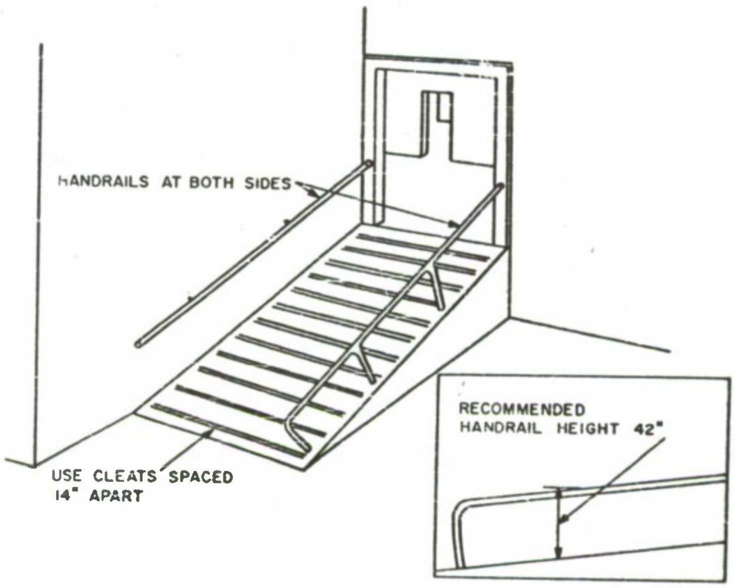
Ramps or inclines are used for grades under 20 degrees. In general (except for outside loading platforms), ramps are of value only when rolling stock must be moved between different levels, and this same space can be used for pedestrian traffic. For pedestrian traffic only, a stairway is more efficient from the standpoint of space, safety, and speed.

For slopes greater than 7 degrees up to 20 degrees, a combination of stairs or ramps and landings is recommended.

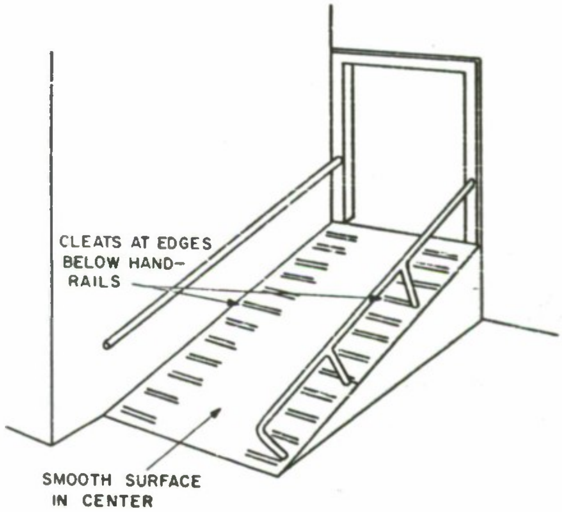
Handrails should be provided at outer edges.

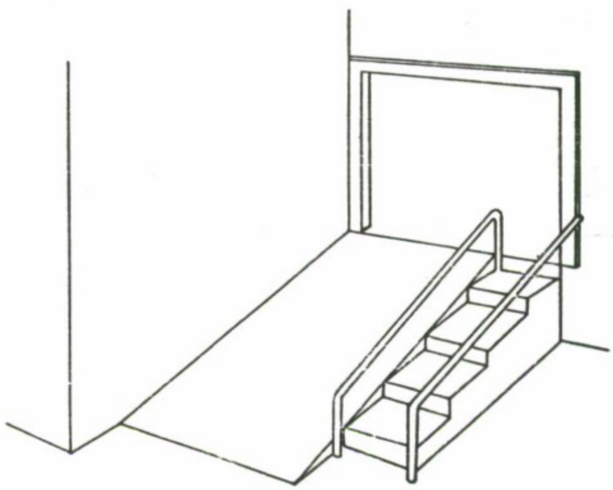
Vertical height above ramp:	38 to 44 inches
Recommended:	42 inches (about elbow height of a short man)

Cleats should be provided on the ramp surface spaced about 14 inches apart, and extending from guard rail to guard rail at right angles to the line of travel.



Where a smooth surface or runway for wheeled vehicles is needed, it should be located in the center of the ramp, with the cleated portions on the outside below the handrails. Otherwise, a combination ramp and stairway is preferred. Ramp surfaces should be nonskid.





d. elevators and escalators

Elevators are used in transporting between floors heavy equipment a a limited number of personnel. They are desirable where heavy mate... or equipment are concerned; and, for personnel, where the distance exceeds two stories. The prevailing standard designs and regulations concerning construction and use of elevators are adequate from a human engineering standpoint, and further discussion is not warranted (19,20,26). In a military situation, elevators for personnel transport are hazardous because they may become nonfunctioning at an inconvenient time. Moreover, they are space consuming and, though their speed may be high, their capacity is limited.

Escalators have a disadvantage, as do elevators, from the standpoint of being incapacitated from mechanical failure, enemy action, etc., and are therefore undependable for moving personnel. However, they can transport large numbers of men rapidly between levels, especially where these levels are longer than one story in height and they can be very efficient, for example, in transferring crews from a rest to a battle station. However, for heights of one story (deck) or less, a stairway is more efficient. Physically sound men can run up (or down) stairs at a rate exceeding that which is safe to use on an escalator.

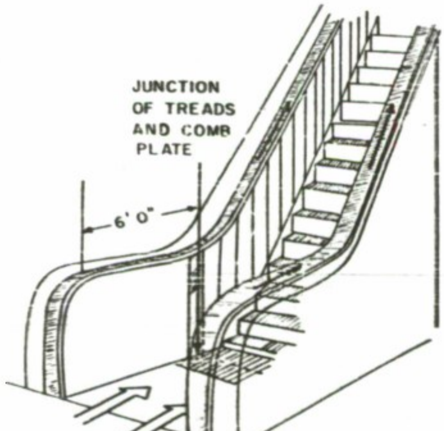
The recommended rate of travel for an escalator is 120 to 138 feet per minute; ranges from 90 to 180 feet per minute may be found.

When entering an escalator at speeds over 120 feet per minute, even experienced users tend to pause to judge their footing. This pause tends to slow passage of traffic to an extent which more than offsets the travel time gained by advancing the escalator rate of travel.

Moreover, when personnel are heavily loaded with equipment (viz., aircraft pilots), too high a travel rate will tend to upset their balance when entering the escalator. (Courtesy Westinghouse Electric Corporation, Elevator Division, and Otis Elevator Company, Escalator Division.)

The preferred angle of ascent is not over 30 degrees. However, 45 degrees is satisfactory in mid-travel provided the angle at entrance and exit is more gradual.

The moving handrail tends to coordinate the user's entering speed with that of the escalator therefore, it should move at exactly the same speed as the steps and, at the entrance to the escalator, it should extend 5 to 6 feet beyond the point where the moving treads begin.



1.3.5 Ceilings, Overheads

Ceiling heights of over 8 feet are seldom available in the military in other than land-based installations. Ships are limited to standard deck-overhead heights except where structure permits a special two-story room; roadable equipment must be built to clear standard overhead structures. The designer, therefore, except in unusual circumstances, must adhere to standard overhead dimensions. He does have the opportunity, at early stages of the design, to locate conduits, plumbing, overhead lighting, air-conditioning ducts, etc., maximizing the utility of the available overhead room. In some cases, it may be possible to offset structural members.

Overhead space design is concerned mainly with the following problems:

a. Location of equipment overhead which:

   1) Can be operated by short operators.

   2) Is out of regular aisles or places where heads will bump it.

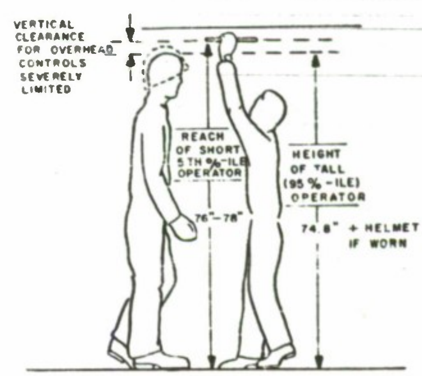
   3) Does not interfere with fixed lines of sight.

b. Establishing clear lines of sight over equipments and/or heads of personnel.

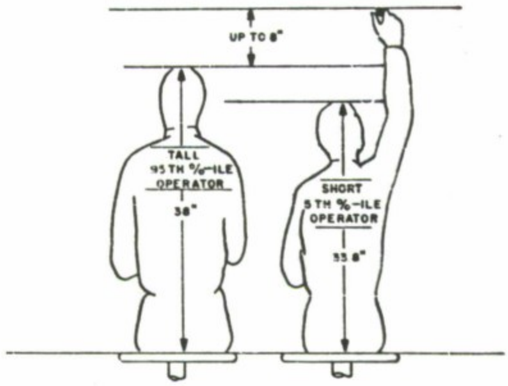
If equipment is located above an aisle, it is restricted to a fairly limited range:

a. Vertical clearance for tall man (plus shoes and helmet): 76 to 77 inches.

b. Height which can be comfortably reached by short man: about 76 to 78 inches depending on type of grasp and strength requirements of controls. (This gives a vertical range of only 1 to 2 inches for most cases.)



In the seated position (such as cockpits), the difference in seated height between the 95th percentile and 5th percentile operator is only 4.2 inches (38 - 33.8 inches). The operator can operate controls comfortably at a height of 10 to 12 inches above his head momentarily, and at 6 inches above his head for longer periods (such as cranking). This gives an area of 6 to 8 inches (vertical dimension) in which equipment can be located.



If the equipment is not operated (or requires only periodic adjustment or maintenance), it can be located anywhere between 76 inches above the floor (head clearance for tall operator) and the overhead.

Where less head clearance (or visual clearance) is required, the minimum height is correspondingly reduced.

The effects of "nonhuman operator" variables on overhead height, such as clearance for vehicles, stacking height for forklift trucks, must be considered whenever these dimensions exceed maximum personnel requirements.

1.4 ENVIRONMENTAL CONDITIONS

It is obvious that, in the establishment of effective working conditions within, and to some extent between, compartments, attention must be given to environmental factors. These factors are considered in great detail in other chapters of this Guide and will, therefore, not be treated here. However, for the convenience of the reader, these environmental factors are listed below:

- Illumination
  - Bright conditions
  - Dim conditions
    - Red illumination
    - Polarized lighting
  - Selective spectrum lighting
  - Access between dim and light areas
- Acoustic Design
- Temperature
- Ventilation
- Humidity
- Vibration
- Acceleration

PART 2
ARRANGEMENT OF MAJOR COMPONENTS WITHIN COMPARTMENTS

Industrial engineers have built up considerable knowledge concerning the placement of machinery, desks, workbenches, surrounding workspaces, the layout of aisles, the volume and direction of flow of men and materials to and from various spaces both within and between compartments.

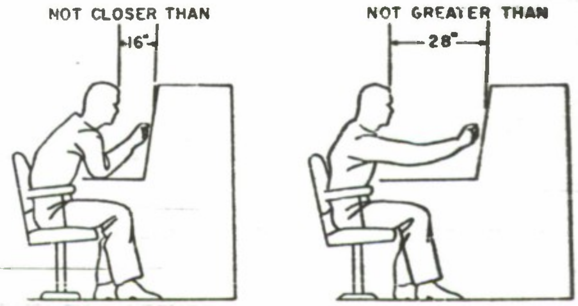
This part does not attempt to duplicate or summarize the literature of industrial engineering. Rather, it adds information concerning the characteristics of the human operator which should be taken into consideration by the design engineer. Generally, this type of information has not been stressed in industrial engineering texts.

2.1 LOCATION OF DISPLAYS

2.1.1 Displays Used by One Operator

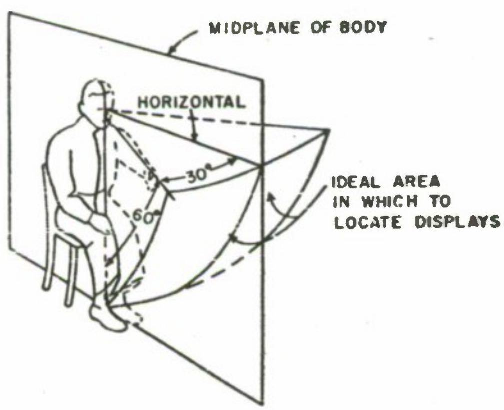
Primarily, a display must be located where an operator can see it (4); then the required detail must have proper size (visual angle), contrast, and brightness in order to be seen (1). The viewing distance should exceed 16 inches in all cases to avoid visual fatigue.

Actual viewing distance is determined in practice partly by visibility requirements and partly by other considerations. For example, the "normal" viewing distance of 28 inches from instrument panels is generally acceptable, but is determined by hand reach where knobs, etc., must be manipulated from a seated position (1). Where remote adjustments are possible, or where displays must simply be viewed, they can be placed at any distance from the operator provided, of course, that they are big enough to be seen at that distance.



For a seated operator, the area of best vision centers around the normal line of sight (4) and is desirable for concentrated attention (such as with radar aircraft scopes or flight instruments).

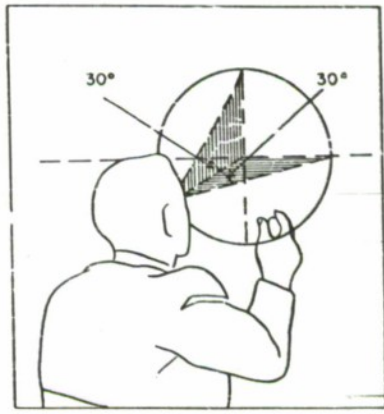
The range of comfortable vision, with the body stationary, is considerably larger. Although exact limits are not rigidly defined (and vary somewhat according to the task), it is generally agreed that the ideal area within which to locate displays is from just below eye level downward 60 degrees from the eyes, and 30 degrees to either side of the midplane of the body (4). Within this area, the operator can easily shift attention from one section to another and still easily see a warning light.



The standing operator has the same field of view except that he is free to turn his body to see anywhere (360 degrees) around him. Nevertheless, it is still desirable to group all primary displays within one desirable visual area as if he were fixed; then additional display groups can be established at one or more other locations, each with its associated controls.

Displays for an individual operator are usually arranged into a single panel (console). In special cases, where large instruments are involved, as with electrical power display boards, these may be arranged as wall displays. The trend, however, is to centralize readings into miniature displays on a single console.

Radar scopes and cathode-ray tubes may be placed above the normal line of sight if they are not used constantly (4). This can be particularly useful when an unobstructed area is needed, such as for looking through a windshield or at a distant central display. Distant displays should be within 30 degrees of the normal line of sight.

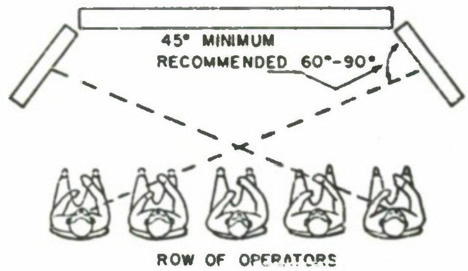


The posture of standing operators is generally more erect than that of seated operators, and displays can be placed directly in front of them at standing eye level. For seated operators, it is best to place major displays at least 15 degrees below the horizontal line of sight.

On consoles, the lower portions may be taken up by controls and thus not be available for displays. In any event, important displays should not be located above the eye level of the short (5th percentile) operator. It is desirable to locate major displays in the upper 20 degrees (horizontal to 20 degrees below horizontal).

2.1.2 Displays Used by a Row of Operators

It is most desirable to look "head on" at a display. Where a row of operators is concerned, this means that the length of the row should be limited and that it may also become necessary to tilt some of the displays. An oblique viewing angle introduces distortion of perspective and parallax error. A viewing angle of 90 to 60 degrees is recommended; 60 to 45 degrees is acceptable; it should never be less than 45 degrees (1). Care should be taken that operators at or near 90 degrees to a display do not suffer interference from their own reflections. Slight tilting of the display in the vertical axis is usually an effective remedy.

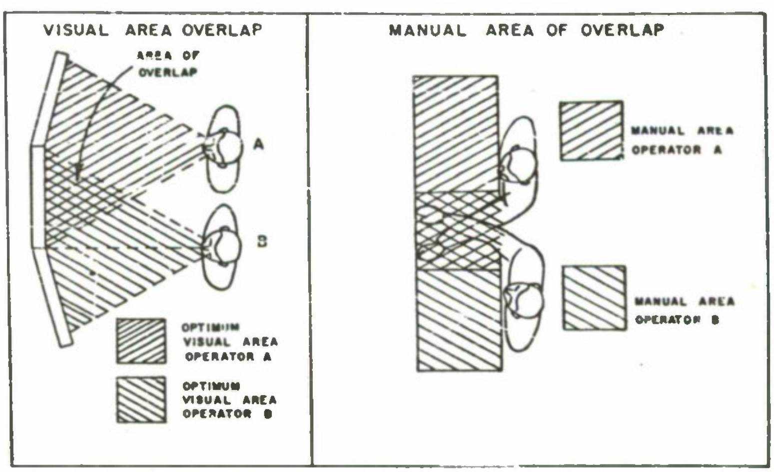


When space is available, two-man teams are usually seated in a row:

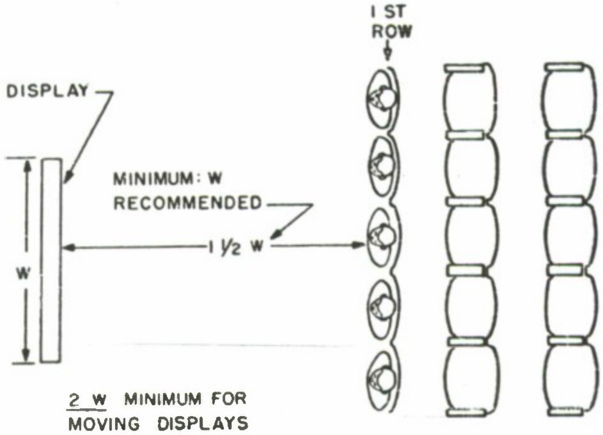
a. Physical separation between operators is small enough so that displays close to them (28 inches or less) can be seen by both.

b. Side-by-side seating makes for better communication (by voice, writing, or manual signal) than a tandem arrangement. Each operator is located within peripheral vision of the other.

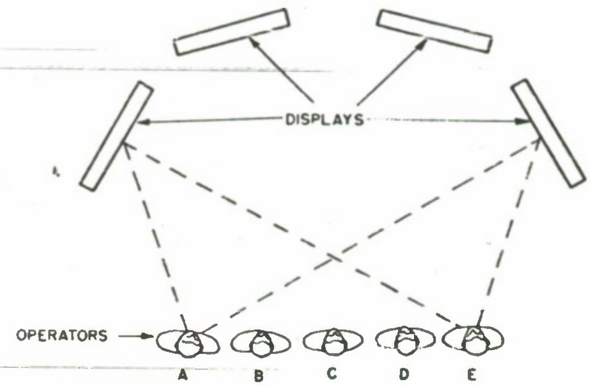
c. A single set of controls and displays is operable and visible by both. This permits standby operation by either of the two operators. Also, their optimum visual and maximum manual operating areas overlap.



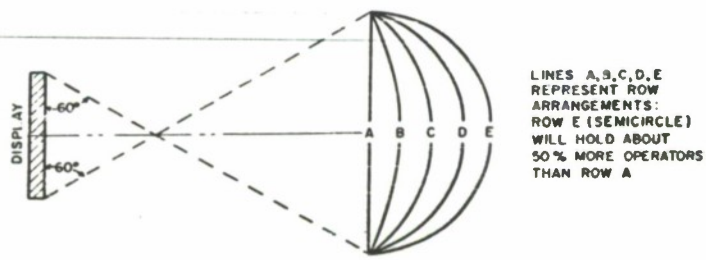
For a stationary display, a row of persons should be seated not closer than the width of the display and preferably not closer than 1-1/2 times the width. For moving displays, this value should be twice the width of the display.



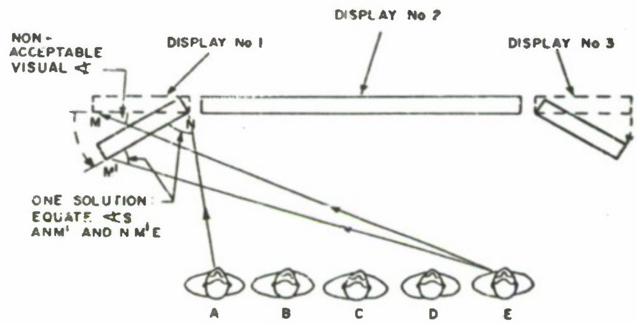
For rows of operators, the standard dimensions for all equipment placements can be determined by the operators at each end of the row. If these are properly placed, the remainder will fall automatically within acceptable range.



A row of operators or equipment may be seated in a straight line or in an arc. The greater the arc (in degrees), the more operators (or equipment) it will hold.

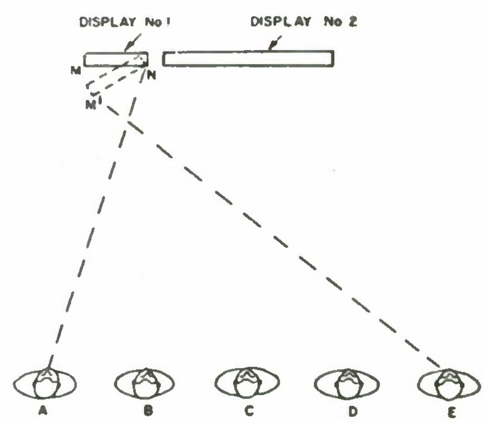


In the accompanying figure, line EM to display No. 1 is the most difficult visual task for operator E. In order to make this better for E, the display is rotated toward him (M moved to M'). This makes line AN (to the same display) a more difficult visual task for operator A. One obvious solution is to equate angles M'NA and NM'E. Another possibility is to maximize the sum of the (M'NA, NM'B, ... NM'E) viewing angles to the displays. (Note that a viewing angle never exceeds 90 degrees, where line of sight is perpendicular to the display surface.) Rather than maximize vision for any particular individual or group, it is preferable to insure first that visual demands of all personnel are above minimum recommended standards. (Provision should be made, of course, that none of these angles is less than 45 degrees.)

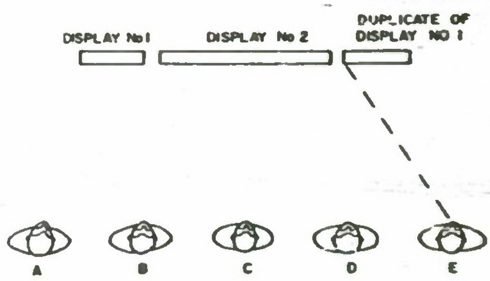


If the displays extend beyond either end of the row of operators, all operators will be benefited. If, on the other hand, the ends of the row extend beyond the limits of the displays, then either

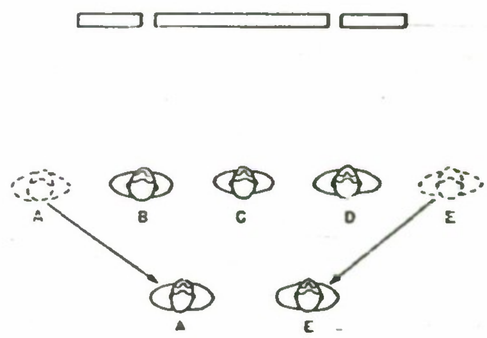
a. Equate angles M'NA and NM'E if both angles are greater than 45 degrees,



b. Or provide a supplementary display for operators seated at opposite extremes of the row to the displays,



c. Or form a second row of operators.



Note that a row arrangement is relatively inefficient:

a. Considerable space is necessary between the first row and major displays.

b. Width of a row is restricted by the visual angle.

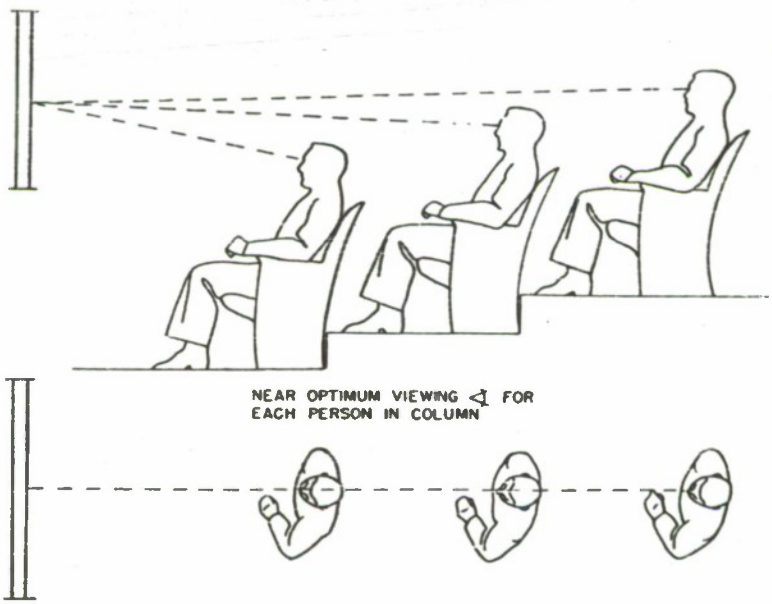
c. Any equipment between the first row and the display must be located so as not to interfere with the operator's vision.

Although a single-row arrangement is practically never used as a method of arranging personnel around a major display (or displays), except for two- or three-man teams, the principles involved in row seating are directly applicable to multiple-row seating.

2.1.3 Displays Used by Columns of Operators

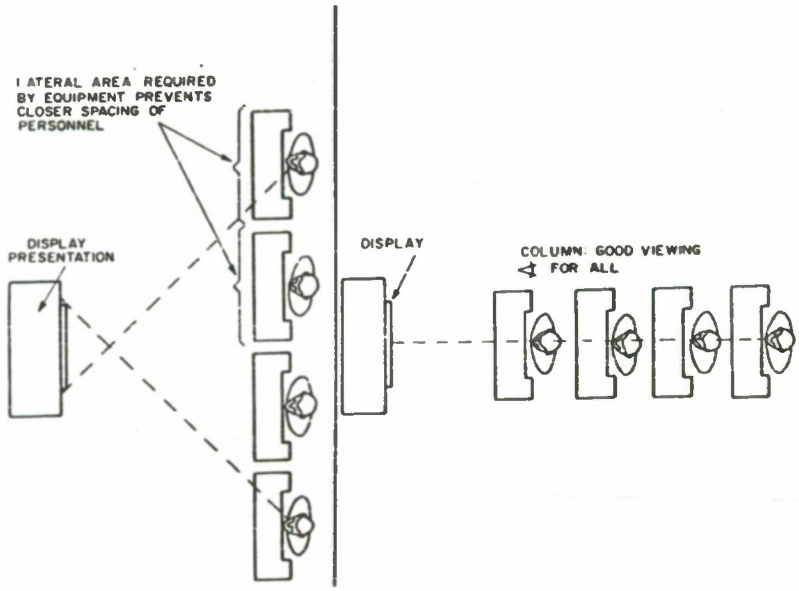
In columns, as opposed to rows, the operators are arranged one behind the other, approximately along a line perpendicular to the front of the display. As with single rows, single columns have little practical usage except for two- or three-man teams. However, the principles of column arrangement are important with respect to massed seating of personnel, where each person must see beyond the person(s) directly in front of him (see also Section 2.1.4).

Columns provide a near-optimum viewing angle for each person in the column, They are limited in that increasing the length of the column increases the distance from the display.



The row arrangement provides approximately equal distance of all observers to the display and also is more convenient from the standpoint of seating. Unless care is taken, the row arrangement gives less satisfactory vision to displays.

A column arrangement is useful where console operators must share a single display jointly, and the width of the consoles precludes an adequate viewing angle where a row arrangement is used.

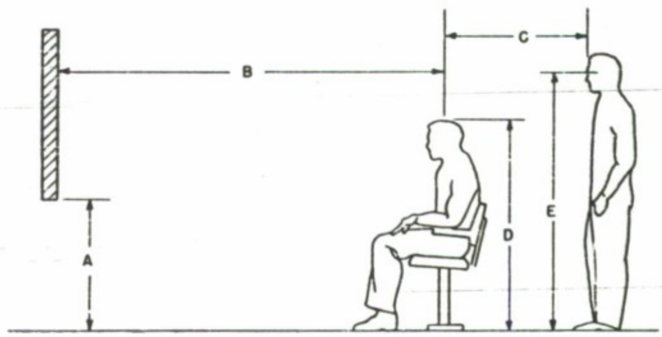


a. standing operators

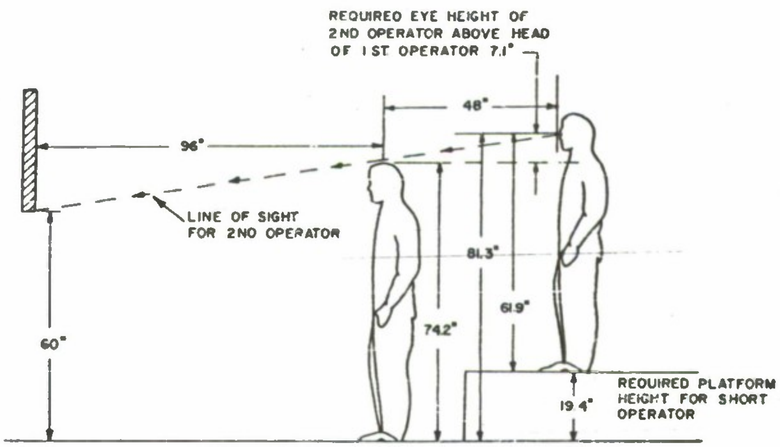
Where an operator must see over the head of the operator in front of him, the following dimensions are involved.*

*Section 2.1.3d, "Staggered Seating," considers the case where an operator views the display over the shoulder of the operator in front

1) Height of bottom edge of display above the floor (A).
2) Distance of front operator from the display (B).
3) Distance between operators (horizontal separation within the column) (C).
4) Head height of front operator above the floor (standing or seated) (D).
5) Eye height of the second operator (E).



With these dimensions, the column seating arrangement can be determined successively for each operator. An example is given below:



1) Height of bottom of display above floor: 60 inches.
2) Distance from display to front operator: 96 inches.
3) Distance between operators: 48 inches.
4) Head height of front operator: 74.2 inches.
5) Eye height of second operator: 61.9 inches.

NOTES

1) Some allowance must be made for the fact that operators vary in height. Therefore, the values used in the above example account for the extreme cases in a normal military population. The front operator is assumed to be a tall man (95th percentile); the second operator is assumed to be a short man (5th percentile).

2) Anthropometric data are generally given for an unclothed man; a value of 1.1 inches has been added to standing height to account for shoes.

3) The standing height of the front operator should be increased to include headgear, if it must be worn.

By subtracting measurement E from D, it is evident that the second row must be elevated 12.3 inches (74.2 - 61.9); this permits the second operator to see horizontally. When the bottom of the display is lower than the front operator's head, an additional increment must be added. The following formula closely approximates this increment

$$\frac{(D - A)C}{B}$$

In this example, this increment would be

$$\frac{(74.2 - 60)(48)}{96} \text{ inches} = 7.1 \text{ inches.}$$

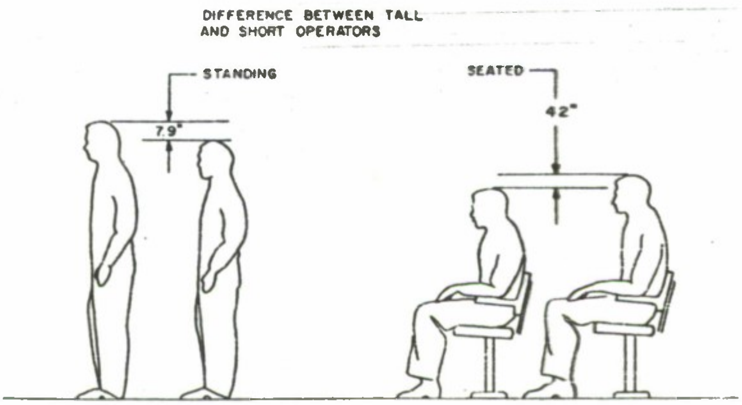
Thus, the second row should be elevated 19.4 inches (12.3 inches + 7.1 inches) above the floor level. Note that, when the bottom of the display is higher than the head of the front row operator, the quantity (D - A) is negative, and the increment is subtracted from the 12.3 inches.

The identical process is used to compute the platform elevation for succeeding rows, calculating the required height for a row with reference to the operator(s) in the row immediately in front.

b. seated operators

As shown above, an arrangement to accommodate standing operators often requires excessive headroom. A seating arrangement will save headroom (and still permit men to see) for three reasons:

1) The differential in height among operators due to leg length is eliminated, leaving only the differential due to the torso; this saves nearly 4 inches headroom allowance for each row.



2) By providing adjustable seats, the tall operator can sit in a lowered seat, while the short operator can sit in a raised seat. This serves still further to decrease the difference in seated height between tall and short operators.

3) The seated operator's eye and head heights are lower than those of the standing operator (about 15 inches on the average for most seats).

The method for calculating the recommended spacing between a column of seated operators is identical to that given for standing operators, provided that appropriate dimensions are used for the seated operator.

Data are provided in Ely et al. (4) to determine seat height and seat height adjustment for various types of working conditions.

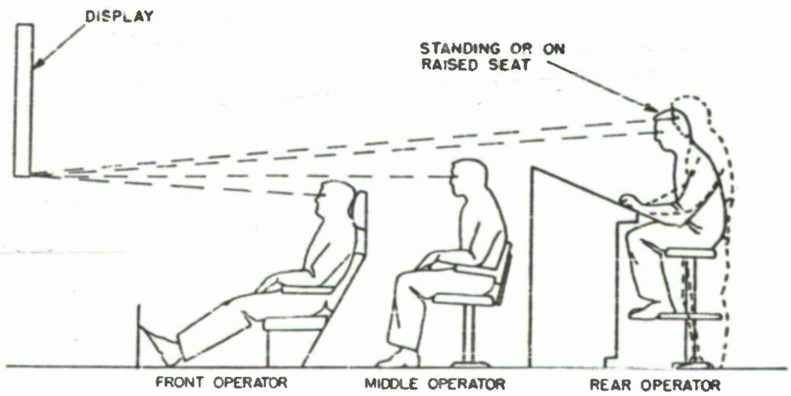
c. special case: standing and seated operators

Where a column of only three to four operators is involved, a further reduction in overall headroom can be made by a combination of seated and standing positions:

1) The front operator can sit in a low seat pan,

2) The middle operator can sit on a standard seat,

3) The rear operator can stand (or sit on an elevated stool).



The method of calculating the required space is identical to that given previously.

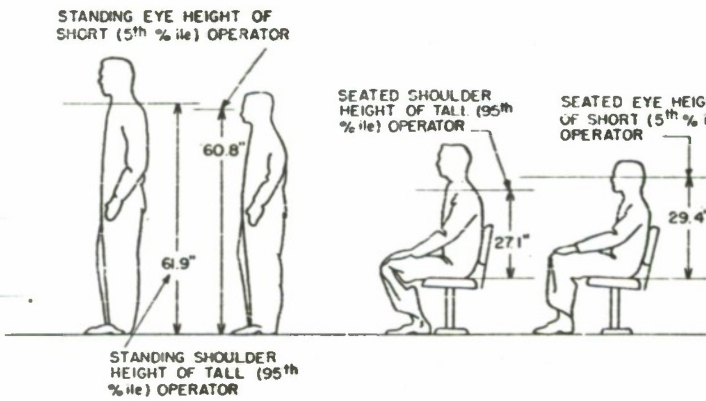
d. staggered seating

The example given above, where a person must see over the head of an operator seated in front, is seldom necessary except where the available space is very narrow. Furthermore, few installations can provide the required ceiling height of over 8 feet. In practice, seats can usually be staggered or offset so that one can look over the shoulder of the person directly in front. The calculation for a "column" in this situation is identical to that given above with the following exceptions:

1) Seat staggering: the amount of offset or seat staggering must be computed.

2) Vertical measurements: shoulder height* is used instead of sitting or standing height.

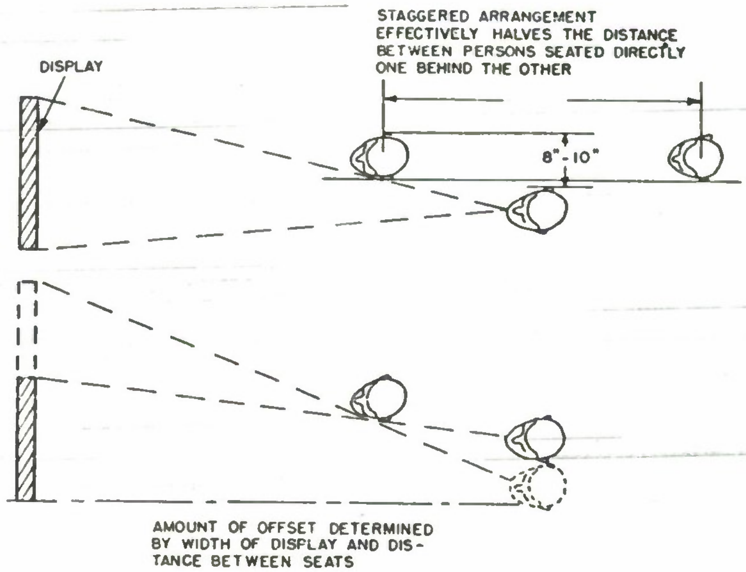
	Standing	Seated
Shoulder height (tall operator)	61.9 inches	27.1 inches
Eye height (short operator)	60.8 inches	29.4 inches



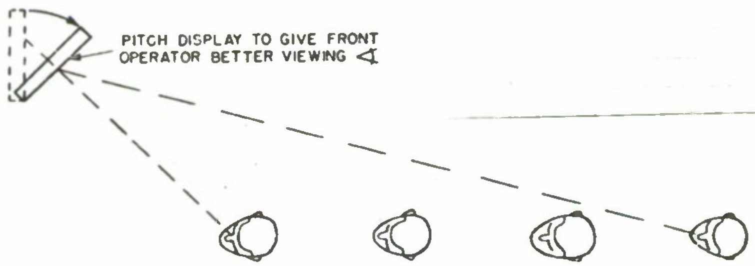
The values for standing heights do not include an allowance for shoes; sitting heights are given from the seat reference point. Shoulder height is usually measured from the tip of the shoulder. Since the shoulder slopes upward to the junction with the neck, the effective height, as given here, is about 2 inches higher than the tip of the shoulder (11).

*Height of shoulder near neck, not to be confused with height of shoulder point (acromion)

A straight column is not the most efficient arrangement. The figure below illustrates the principle for arranging a column to insure proper visual clearances; each individual in the column must be offset* by approximately a head's width to obtain a full view of the display. Effectively, the result of staggering the seating is to halve the between-row distance required for persons seated directly behind on another in a column. Vertical clearances are calculated by the method previously described.

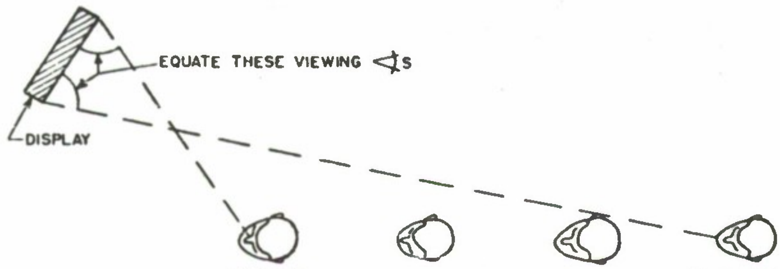


By offsetting displays, special seating requirements can be circumvented. The amount of offset should be determined by the degree of vision desired for the last person in the column. If this person has a full view beyond the head and shoulders of the person directly in front of him, the view for the others will automatically be clear. It may be desirable to pitch the display a few degrees to give the front operator a better viewing angle.



*Amount of offset is determined by width of the display and front-to-rear distance between operators

A good general rule is to equate the viewing angles for the front and rear operators; then, those in between will also have an acceptable visual angle.

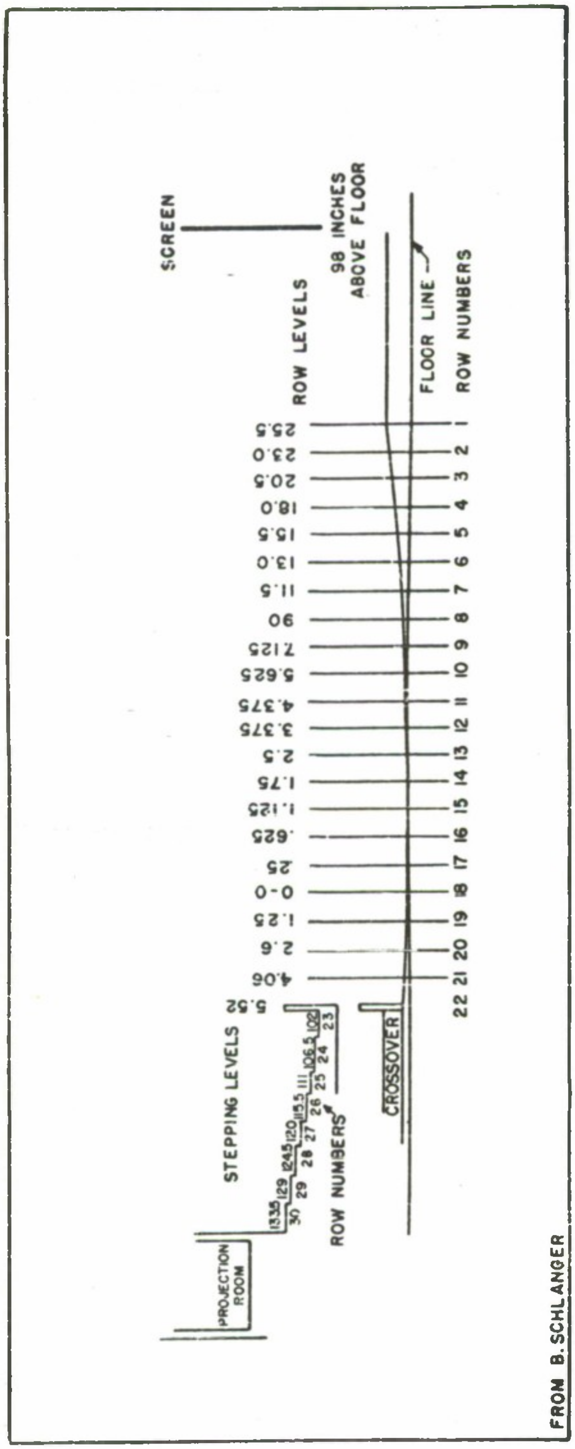


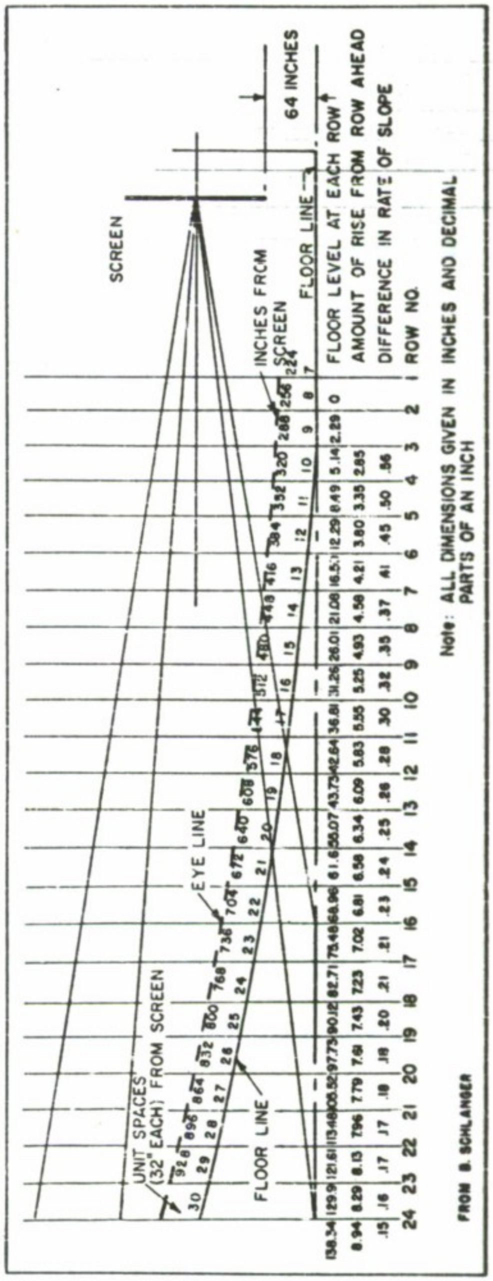
2.1.4 Displays Used by Large Groups of Operators (Multiple Rows or Columns)

In general, the principles discussed in the preceding sections (2.1.1 through 2.1.3) may be applied to building up multiple columns and rows for seating large groups of operators. For such an application there are several special considerations:

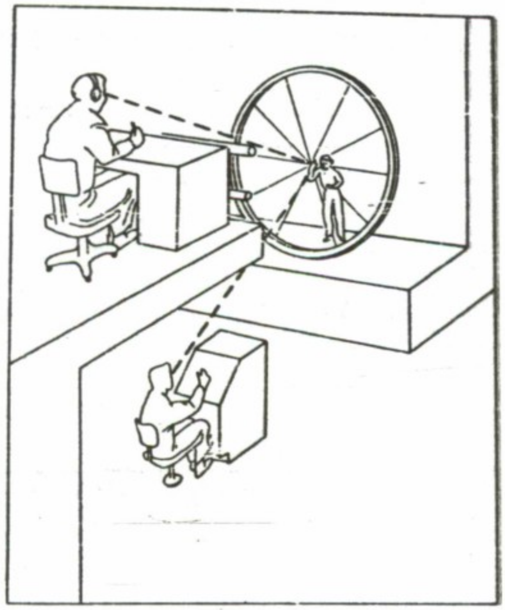
a. The floor elevation can be specially structured, with a reverse incline for the first few rows.* This will save some ceiling height.

*Reverse curve depends on the number of rows. See Schlanger (13).


SCREEN
98 INCHES ABOVE FLOOR
ROW LEVELS
FLOOR LINE
ROW NUMBERS
STEPPING LEVELS
ROW NUMBERS
PROJECTION ROOM
CROSSOVER
FROM B. SCHLANGER


SCREEN
64 INCHES
INCHES FROM SCREEN
FLOOR LINE
EYE LINE
UNIT SPACES (32" EACH) FROM SCREEN
FLOOR LINE
FLOOR LEVEL AT EACH ROW
AMOUNT OF RISE FROM ROW AHEAD
DIFFERENCE IN RATE OF SLOPE
ROW NO.
Note: ALL DIMENSIONS GIVEN IN INCHES AND DECIMAL PARTS OF AN INCH
FROM B. SCHLANGER

b. Some operators can be placed on a balcony, either at the back or sides of the chamber.



c. Some provision must be made for aisles, thus breaking up a solid seating arrangement.

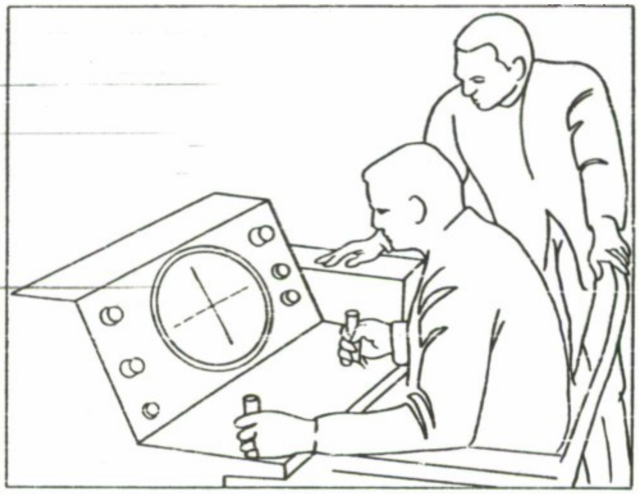
2.1.5 Displays Used by Stationary Operators, Mobile Observers (See also Section 2.2.3)

Primary displays which must be used by both a console operator and a mobile observer (e.g., supervisors, liaison officers) cannot be optimally located for both men at the same time, and hence a compromise is always involved.

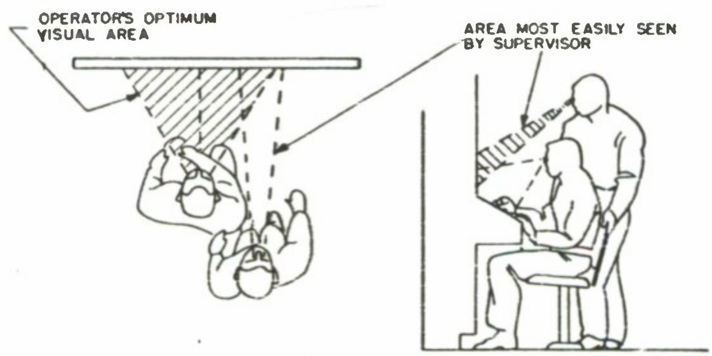
The stationary operator, who is not at liberty to find an acceptable position, should receive primary consideration.

a. locate display within, or as near as possible to, the operator's optimum visual area

Primary displays should be located within the stationary operator's optimum visual area, even at the expense of some inconvenience to the onlooker, since the latter is mobile and more adaptable. There is almost no location of a display within the operator's visual area which an onlooker cannot also get in position to see.



The optimum location for the panel area for which the supervisor is responsible is at the upper right or left corner of the operator's optimum visual area (depending on which side of the operator the supervisor is located). To get the best view of the operator's activities, the supervisor will stand to one side and slightly to the rear of the operator, looking over his shoulder. Displays placed less than 28 inches from the operator will benefit the supervisor accordingly.



b. maintain control-display compatibility

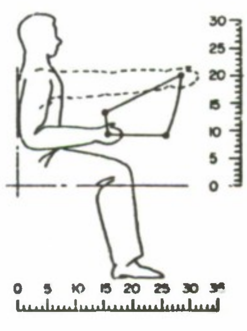
Controls should be placed with regard to the operator and not the onlooker. They should be logically grouped near the instruments with which they are closely associated and with which they are most often used, in accordance with individual operator design considerations discussed at length in Ely et al. (3).

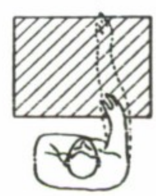
2.2 LOCATION OF CONTROLS

2.2.1 Controls Used by One Operator

This subject is discussed in detail in other chapters of this guide (3,4) both for manual and pedal controls, and only basic information will be provided here. The design of controls for a single operator will generally apply to the design of individual stations for members of a team.

The following area is optimum for an operator, whether seated or standing. [Note that optimum dimensions, for the most part, are derived from the body measurements of the small (5th percentile) operator. This makes the area optimum for almost the entire operator population.]

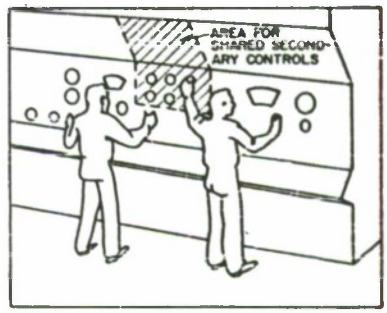




The area defined by maximum manual dimensions is much larger in the standing than in the seated position due to the fact that the standing operator can bend over as well as reach overhead. In addition, there is a theoretically unlimited lateral range which the operator can attain by walking to different control locations.

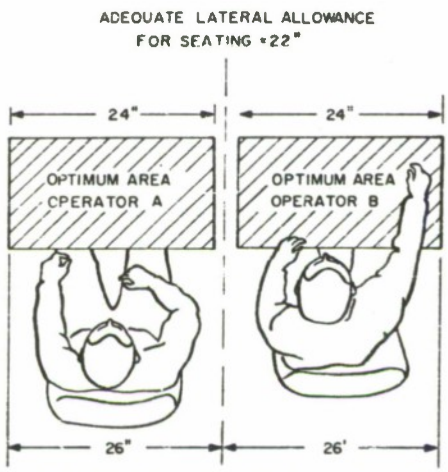
2.2.2 Controls Shared by Two Operators

Secondary controls, such as on-off switches, setup and adjustment controls, speaker volume controls, can be shared and present few design difficulties. These may be located outside the optimum operating ranges of both operators but within nearby overlapping areas.



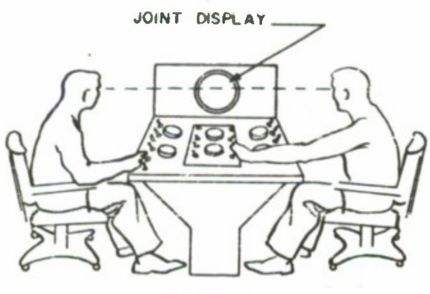
The sharing of primary controls by two operators should be avoided wherever possible because of the following disadvantages inherent in shared controls:

a. Since the overlap of optimum manual areas is negligible or nonexistent for two persons seated side by side, shared controls must be limited to a very small area.

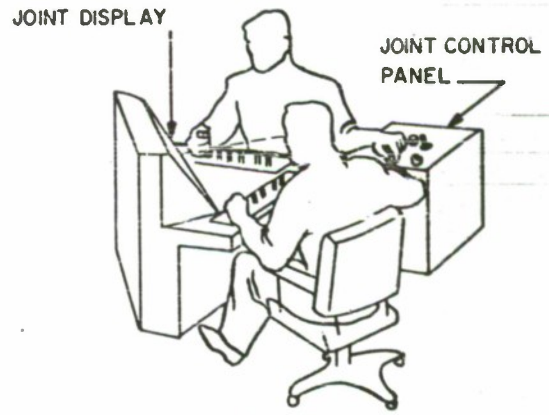


AREA OF OVERLAP: NOTE THAT OPTIMUM MANUAL AREAS DO NOT OVERLAP IN SIDE-BY-SIDE SEATING ARRANGEMENT, WIDTH OF OPTIMUM AREA IS ABOUT 24" WHICH IS LESS THAN RECOMMENDED LATERAL ALLOWANCE FOR SEATING.

The possibility of sitting at right angles or face to face for joint operation of controls may exist for some applications.



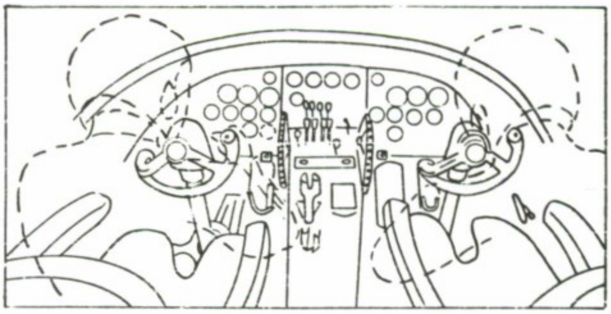
FACE TO FACE



RIGHT ANGLE

b. Controls which are shared must be used by the left hand of one operator and by the right hand of the other. This may lead to confusion if they change places or if an operator may be required to fill either position.

When primary (i.e., continuously monitored) controls must be shared (as in an airplane), it is recommended that a duplicate set be given to each operator. Note that, to insure proper coordination of both controls, this leads to an additional complication requiring either a system of interlocks or a standard operating procedure (which requires training).



2.2.3 Controls Used by a Stationary Operator, Mobile Observers (See Also Section 2.1.5)

This section describes the location of controls which are of primary importance to the operator stationed at a workplace, but which must occasionally be monitored and/or operated by other personnel. First priority must be given to the requirements of:

a. the regular operator

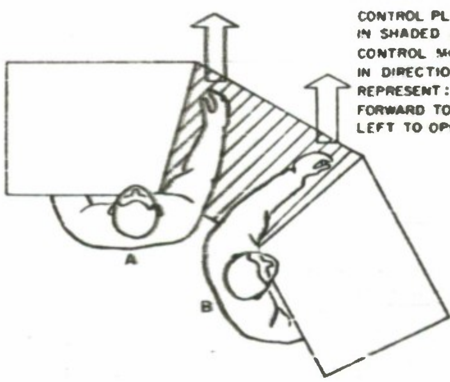
If the control is of primary importance to his job duties, then it must be placed within his optimum manual area.

b. control-display compatibility

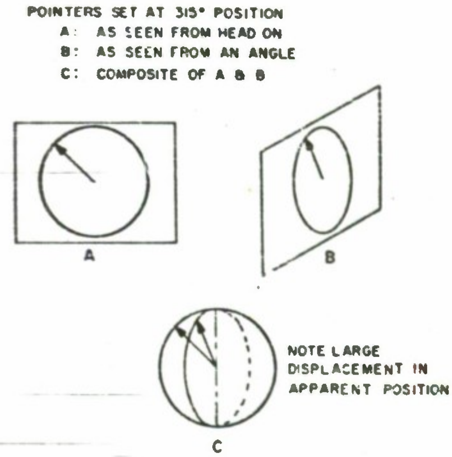
The location, placement, and manner of operation of the controls must be consistent with recognized design principles (3). The controls should be located in relation to other controls and displays in a manner which optimizes ease of learning and ease of operation. As an exception, a single control can sometimes be taken out of the context of related controls. The learning problem itself, or the probability of making control errors, is seldom increased by a single exception. By its uniqueness, the exception tends to reinforce learning associations.

In general, only emergency controls and displays should be separated from their associated instruments (4). Although the removal of controls and displays from their normal context may make them more accessible to supervisors and/or other operators, too much separation makes for a cluttered, hard-to-operate arrangement; and, if any displays and controls are to be so separated, priority should be granted to those associated with emergency operations.

In order to keep control activation compatible for both operator and supervisor, both should face in approximately the same direction (within 30 degrees of each other).



CONTROL PLACED IN SHADED AREA. CONTROL MOVEMENTS IN DIRECTION OF ARROWS REPRESENT: FORWARD TO OPERATOR A LEFT TO OPERATOR B

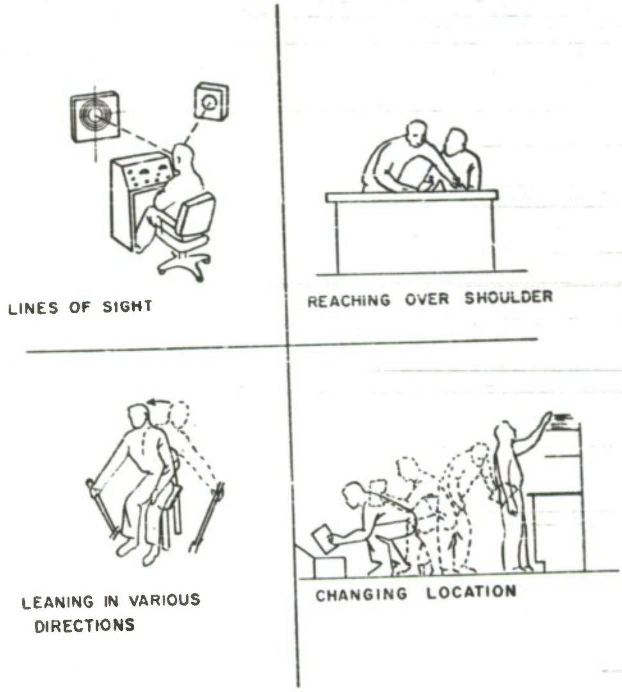


As this angle approaches 45 degrees, direction of control movements becomes ambiguous (4). This is particularly undesirable where any two-dimensional tracking task is involved.

If any such duty must be shared, it is recommended that two displays be provided so that each operator can face his own console squarely.

Design Notes

In laying out the controls and displays for an operator and supervisor (or other operator beside or in back of him), it will usually be necessary to work out some compromise in which each of the men must work partly outside of his optimum area (visual and manual). There are many possible solutions to this layout problem and the use of anthropometric tables is laborious and time consuming. The use of two- or three-dimensional models is recommended both for investigating numerous possibilities in rapid succession and for gaining insight into altogether new approaches to the layout problem. Three-dimensional, articulated human figures and small-scale models are especially beneficial in determining such various possible combinations as shown in the figures below.


LINES OF SIGHT
REACHING OVER SHOULDER
LEANING IN VARIOUS DIRECTIONS
CHANGING LOCATION

2.3 PLOTTING BOARDS AND STATUS BOARDS

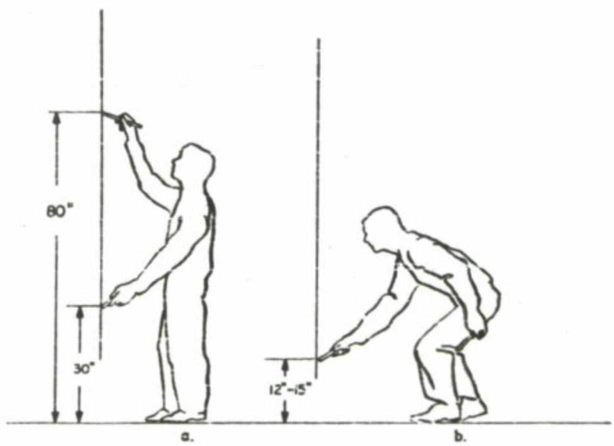
2.3.1 Manual Plotting

This section deals with plotting boards and status boards from the viewpoint of placing information on them (as if this were a "control" function). Status and plotting boards must be maintained by operators, and the placement of these facilities influences the room design and placement of other items of equipment. Considerations with regard to display are considered in Section 2.1 and in Chapter II of this Guide (1).

The operator-plotters have certain space requirements and minimum limits within which they can operate effectively. These limits are determined by the following considerations:

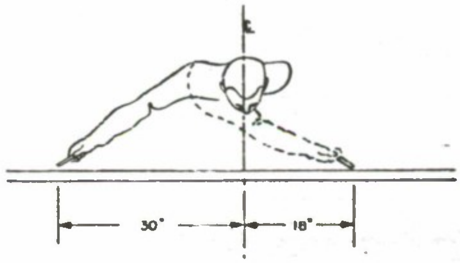
a. physical reach limits

The required dimensions will depend on the size and location of the plotting area which the operator is required to maintain. The standing operator can optimally maintain without stooping a rectangular area extending vertically from approximately 30 inches to 80 inches* above the floor level; stooping will extend the lower limit to within 12 to 15 inches of the floor.

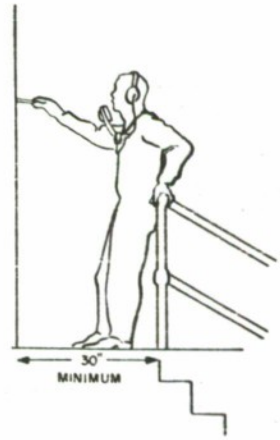


*The upper 95 percent of the male military population can reach this height with a grease pencil or similar plotting implement.

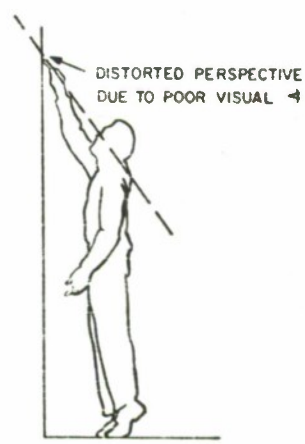
The horizontal extent depends on the lateral movement the operator is allowed. The right-handed, stationary, standing operator can comfortably plot (within the vertical dimensions given above) from 18 inches left of the centerline of his body to 30 inches right of this line.



The standing plotter should have a minimum of 30 inches clearance front-to-back. Preferably, he should also have a back rest (or guardrail) against which he can lean.



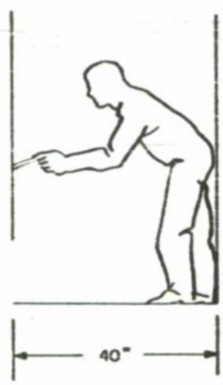
While most* plotters can reach higher than 80 inches, this is not recommended since it would require the short operator to stand on tiptoe or with the body against the plotting surface. This makes writing movements awkward and gives the plotter a distorted perspective of the plotting surface.



*The upper 95 percent of the male military population can reach this height with a grease pencil or similar plotting implement.

In order to plot on the area below 30 inches from the floor level, additional front-to-back room must be provided in order to allow the plotter to bend from the waist or to kneel.

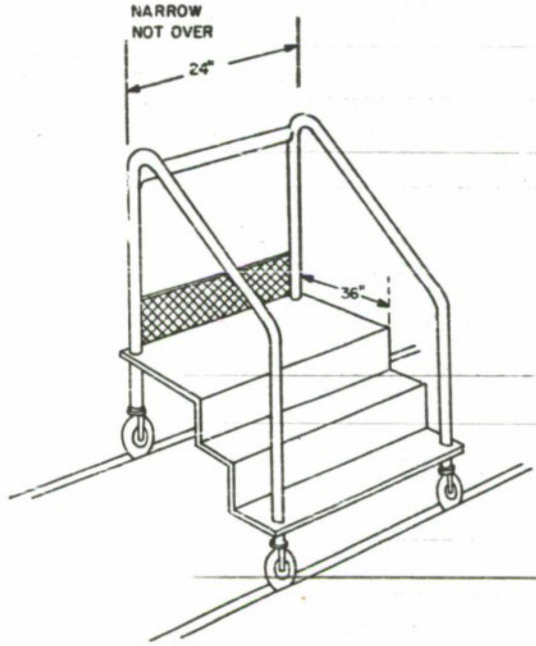
Bending forward from waist:	Allow 40 inches
Kneeling:	Allow 45 inches



b. structural aids

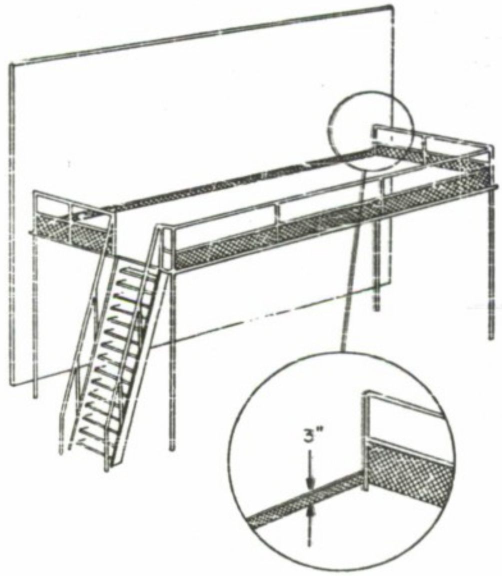
In order to increase the normal vertical coverage of the plotter, various structural devices are used, such as ladders, platforms, elevators.

1) Ladders: These are generally unsatisfactory because they are inherently unsafe and are cumbersome to move and position. However, when a single operator must maintain a large plot which extends above his normal reach, a movable platform with attached steps is recommended. The platform should be narrow (not over 24 inches wide) and at least 36 inches deep with guardrails at the sides. It should be of light, rigid construction and should move on tracks for easy positioning. One recommended design is illustrated in the following figure.



2) Platforms and Scaffolds: An elevated structure is satisfactory where one or more operators must remain stationed above the floor level. The following design features are recommended (2):

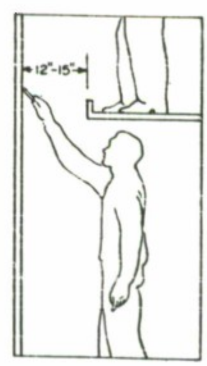
a) Two-level guardrails should be provided at the rear and sides with wire mesh between the platform and bottom guardrail. The front edge of the platform should be provided with a guard strip at least 3 inches high (to prevent the operator from stepping off the platform, and to prevent articles on the platform floor from falling off).



b) Platform levels should be spaced so that the plotters' tasks are evenly divided (insofar as can be planned in advance).

c) Platforms should be designed so that more than one plotter can work on the same platform when the work load becomes excessively heavy in that sector.

d) Platforms should be located so that the plotter on the level below can cover the plotting sector up to 12 inches above the level of the platform above. The vertical distance between levels ideally should not exceed the standing height of the plotter by more than 2 to 3 inches. The distance between the plotting surface and the front edge of the platform should be between 12 and 15 inches. This allows a plotter adequate room to plot on surfaces up to 12 inches above the next platform level, thus relieving the operator on the next level from maintaining this hard-to-reach area.



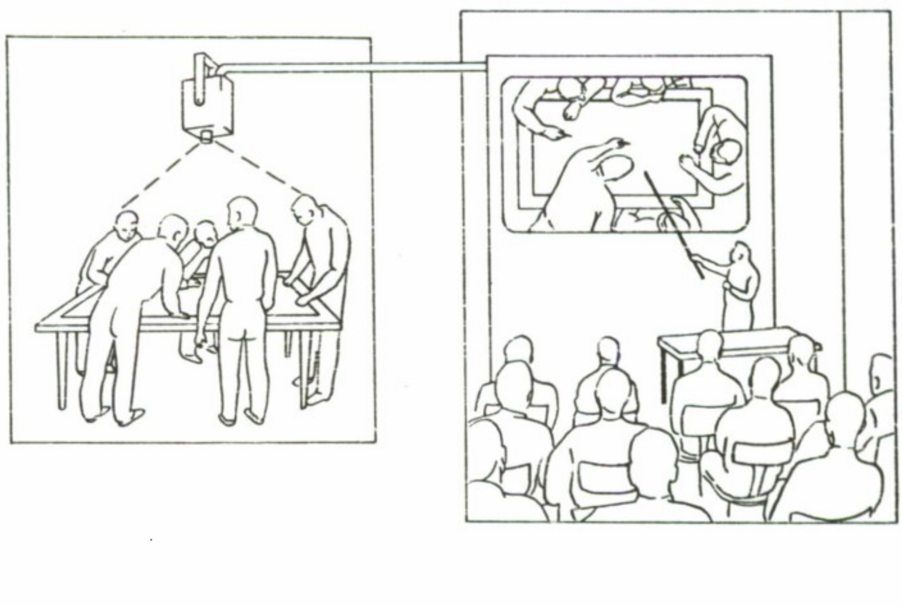
3) Elevators: Elevators which move both vertically and horizontally and other elaborate mechanisms have been used where a single operator is responsible for maintaining the plot on a very large surface. Here the primary consideration should be the safety of the operator. If possible, the device used should position the operator within the reach limits of the standing operator recommended in Section 2.3.1a. The operator should not be required to move more than a step from the platform controls on a moving platform. The platform should have two-level guard-rails on all four sides (operator enters through gate).

c. rate and density of plotting information

The operator rapidly loses efficiency when he attempts to plot beyond a certain rate (8). If the information comes in at a high rate and in a constricted plotting sector, the plotter can maintain only a small area. In this case, the dimensions of the sector assigned to the plotter should be governed by the anticipated peak load rather than by anthropometric considerations.

2.3.2 Automatic Displays

Electronic displays or plots have been developed which take information on a programmed time-sharing schedule from a variety of sources and plot this information automatically. The display may be plotted on paper, for instance, projected on a screen or cathode-ray-tube, etc. Moreover, the geographical positions of the plotted information may be supplemented by a wide variety of coded information.



The main advantages of these systems include:

a. Minimizing of operator error. Automatic equipment can handle information at a rate at which a team of operators would either omit or misinterpret incoming information.

b. Minimizing of lag times. Automatic equipment can: 1) plot at faster rates than human operators, 2) store information when lags occur and 3) bring the plot up to date promptly and accurately when the rate of incoming information slacks off.

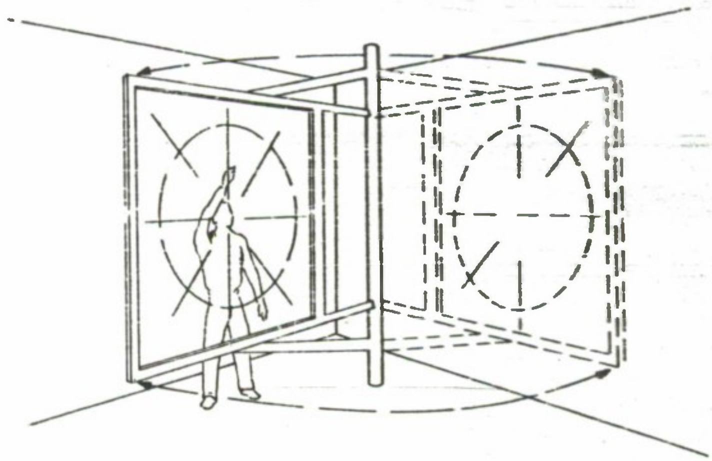
c. Ability to duplicate displays in several locations and to any desired scale. The full picture can be split, individual sectors expanded, information selectively screened by electronic or optical filters, etc.

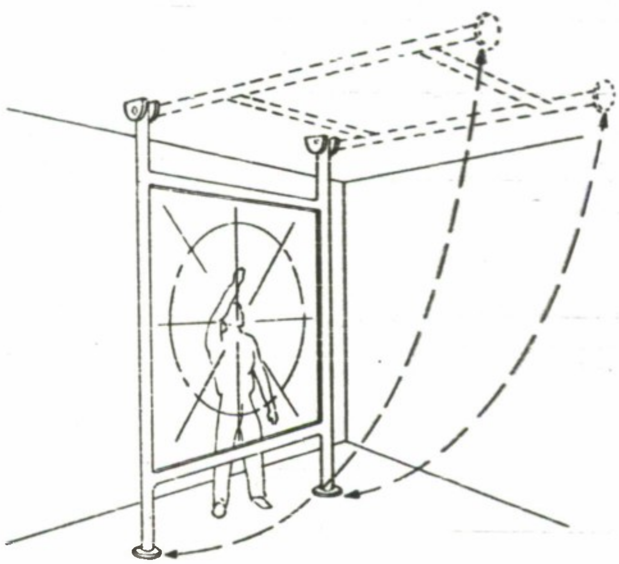
d. Manual plotting operations can be performed at a remote location, removed from the dense traffic in priority areas.

The chief disadvantage of all such equipments is their complexity and inherent unreliability, which tends to increase as more and more of the advantages listed above are built into the system. The optimizing of such systems by balancing out the unreliability disadvantages against the speed, accuracy, and multiple information capabilities is beyond the scope of this chapter. Nevertheless, with any highly automatic system, it is desirable to provide standby manually operated facilities which are independent of electronics except for the primary target-sensing equipments.

The standard manually operated vertical plot is practically immune to breakdown (other than in the technical sense of operator overload) as long as the primary information-gathering sources are functioning.

Therefore, the layout should include auxiliary manual plotting facilities which: 1) can be positioned quickly for emergency use, and 2) take up a minimum amount of operating room (when the regular information display systems are operating normally). Auxiliary display boards may be wall mounted, or otherwise stowable, by hinging, swinging brackets, floor-mounted fittings and brackets, etc.



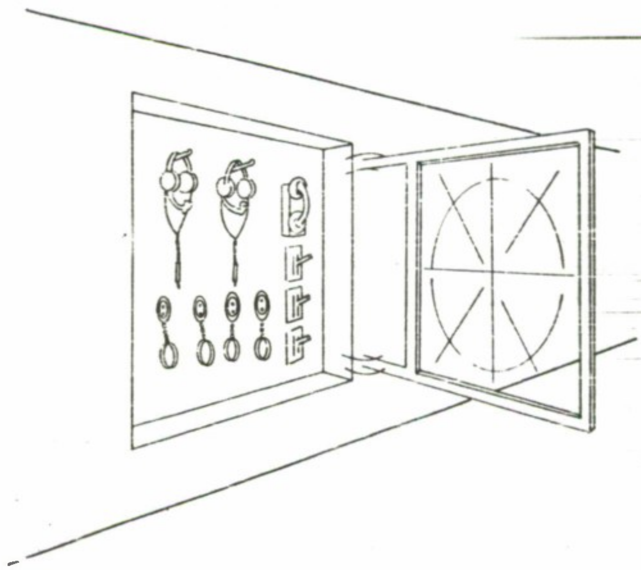


Portable or stowable boards should be attached to a wall, etc., rather than to a heavy, portable base which allows them to stand upright (as found on a movable blackboard). Such a base adds considerably to weight and bulk, and results in a loss of portability. Moreover, such supports are not stable enough for use in moving vehicles. Provided space is available, the display should remain mounted where it will be used:

a. Less assembly time is required than for portable displays.

b. There are fewer loose parts which can be mislaid, etc.

The advantage of a portable display is that, apart from restrictions on arrangement of equipment, little or no prearranged space is required. Placement of this board can fit in with natural open spaces between items of equipment. However, note that, wherever the plot will be, electrical outlets, headsets and phone and/or radio outlets, intercom circuits, plotting equipment, etc., must be provided and ready for emergency use.



2.4 LOCATION OF MAINTENANCE SPACES

2.4.1 Working Positions for Maintenance Personnel

In laying out a workspace, consideration must be given to the methods by which the equipment in it will be maintained, especially if additional space will be required to perform this operation (5).

The space provided for maintenance is not primarily a convenience; it is a requirement in order to insure some specified level of operating efficiency. Various philosophies and data exist with regard to the importance of maintenance. Certain equipment may be used without maintenance until it breaks down, at which time it will be discarded; other equipment may require constant and continual maintenance even while it is being operated. No attempt will be made here to arrive at decision rules for the appropriate degree of maintenance. For convenience, it is assumed that it is required, and data are given in Table VIII for the space and clearances that must be provided for various body positions assumed by the operator while making adjustments and conducting maintenance.

TABLE VIII
Minimum recommended clearances (inches)
Working on vertical surface (clearances needed for tools, "creepers" or dollies should be added).

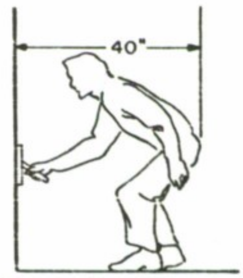
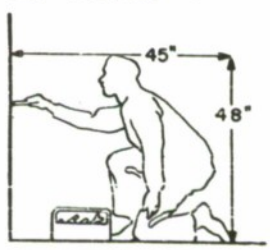
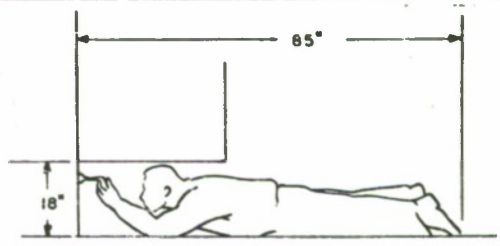
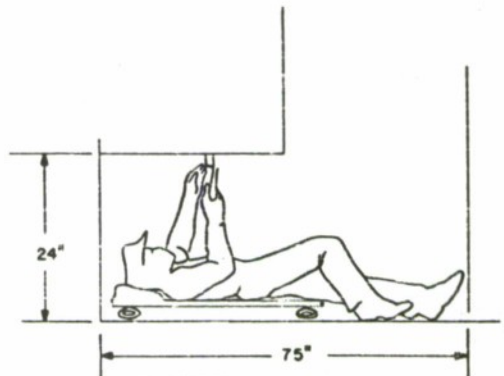
Position	Vertical	Horizontal	
Standing	74	30	 (a) STANDING - WORKING ON VERTICAL SURFACE
Bending over	---	40	 (b) STANDING - BENDING
Seated	52	36	 (c) SEATED
Kneeling	48	45	 (d) KNEELING

TABLE VIII (Cont'd)
Minimum recommended clearances (inches)
Working on vertical surface (clearances needed for tools, "creepers" or dollies should be added).

Position	Vertical	Horizontal	
Prone	18	85	 a) PRONE
Supine (working on overhead horizontal surface)	24	75	 b) SUPINE

In addition to the vertical and horizontal clearances, at least 30 inches lateral clearance is required to provide the operator with "elbow room."

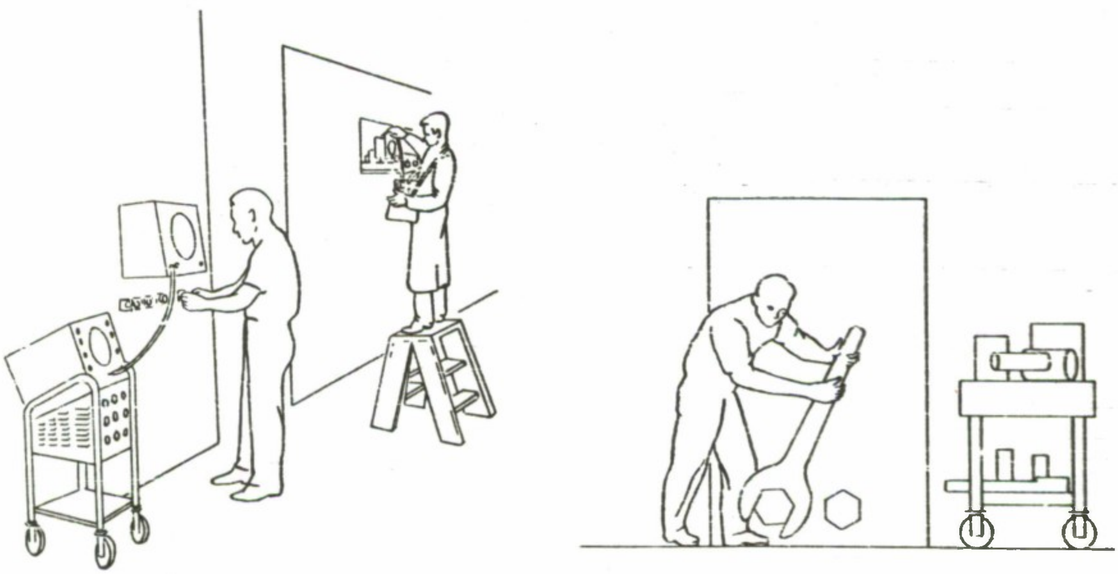
The operating clearances recommended in Table VIII should be unobstructed spaces measured from the maintenance surface to the nearest opposing surfaces. Additional clearance should be given when these opposing surfaces contain:

a. Controls such as toggle switches, levers, which may be inadvertently bumped or kicked.

b. Instrument faces, glass panels, or other objects which are breakable.

c. Protruding objects against which clothing can be snagged.

Maintenance room must also include space for temporary storage or operation of special equipment, such as: a) test meters (instruments), b) large wrenches or other tools, c) work stands, d) step ladders or dollies, e) electrical patch cords.



When facilities for such maintenance are thoroughly developed along with the equipment, then special tools, instruments, and attachments to standard tools or instruments can usually be designed concomitantly at a minimum cost. If the designers know the overall purposes for which the equipment will be used and the likely space which will be allotted to it, they can also develop space allowances for use of:

a. Standard tools, for relatively unlimited operating room.

b. Special tools, where only limited room may be available.

2.4.2 Equipment Space

Equipment can, and should, be designed to facilitate effective maintenance even with a minimum of supporting equipment. A great deal of development has been made in this line, notably with large and complex electronic equipment. Except for power supply equipment and large cathode-ray tubes, the individual components are generally small and light; the circuitry connecting the components is highly flexible and adaptable. This allows compactness of design and multiple tiers of interrelated components. The use of etched or printed circuits is a special development which is not discussed in this section, except to note that this technique not only reduces equipment size, but also aids maintenance problems by: 1) eliminating wiring, and 2) facilitating stacking, removal, and replacement of components.

Some of the newer techniques include the chassis as an integral part of the frame and skin of the overall unit:

a. Lift tops (with chassis attached).

b. Pull-out shelves or drawers.

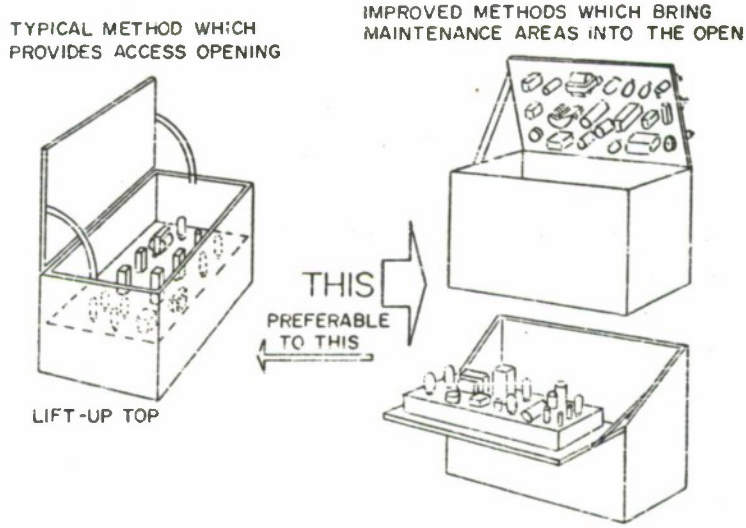
c. Drop tops or sides.

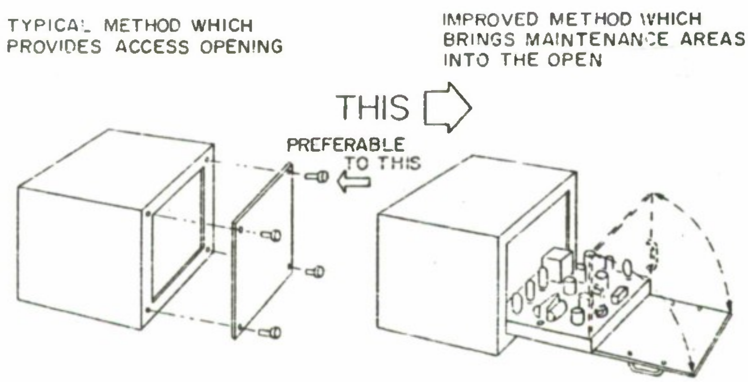
The general use of these is relatively new, replacing the older standard forms, such as:

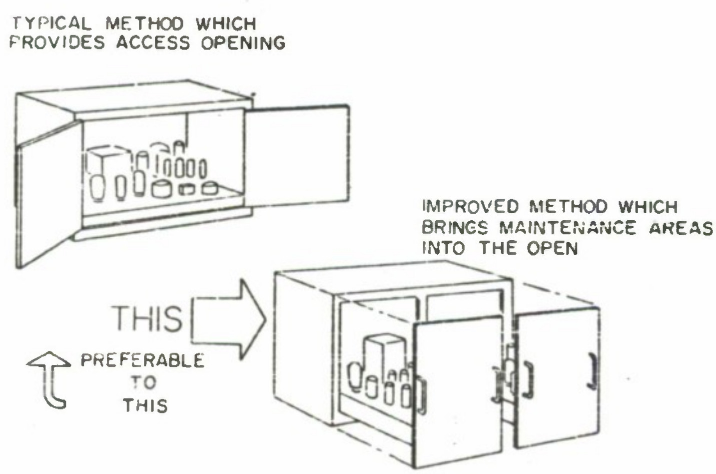
a. Swing-up tops.

b. Access doors.

c. Removable panels.


TYPICAL METHOD WHICH PROVIDES ACCESS OPENING
IMPROVED METHODS WHICH BRING MAINTENANCE AREAS INTO THE OPEN
THIS
PREFERABLE TO THIS
LIFT-UP TOP


TYPICAL METHOD WHICH PROVIDES ACCESS OPENING
IMPROVED METHOD WHICH BRINGS MAINTENANCE AREAS INTO THE OPEN
THIS
PREFERABLE TO THIS


TYPICAL METHOD WHICH PROVIDES ACCESS OPENING
IMPROVED METHOD WHICH BRINGS MAINTENANCE AREAS INTO THE OPEN
THIS
PREFERABLE TO THIS

The principal advantage inherent in the newer methods lies in the fact that the operating components (or "guts") of the equipment can be brought out into the open, exposing several sides for access, with a minimum of space and fewer obstructing partitions intervening between the components and the maintenance operator. The older standard methods, on the other hand, merely provide acc openings to these equipment components.

2.4.3 Advantages and Disadvantages of Various Maintenance Features

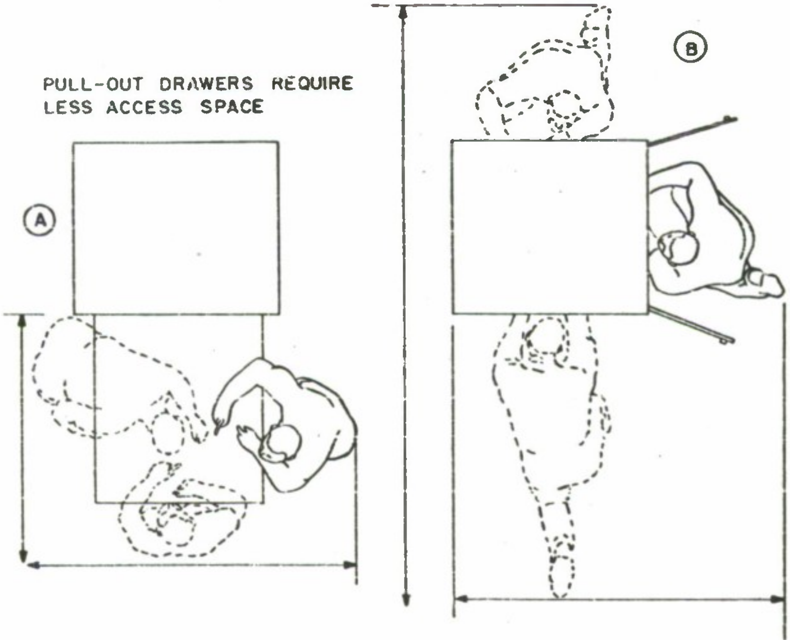
a. accessibility

The pull-out drawer arrangement is generally superior, particularly when the drawer front folds down or is removable.

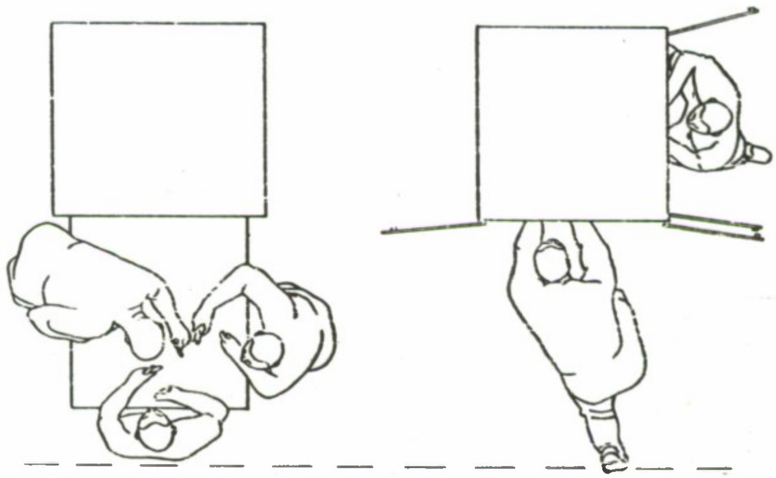
The principal advantage of the newer designs is the ease of accessibility to all components, particularly those located at the rear of the chassis.

1) Removable panel openings are satisfactory for servicing components which lie in a plane parallel to, and within 6 inches of, the opening (such as terminal blocks). This is also true for swing-out doors, but the door require clearance space for opening.

2) Most arrangements whereby the maintenance operator must go inside the main frame of the equipment (as opposed to pull-out drawers, etc.) do not actually save space. The maintenance operator has only one means of access to the equipment and his position generally requires more space than if the equipment could be pulled out.


PULL-OUT DRAWERS REQUIRE
LESS ACCESS SPACE
A
B

3) In the pull-out drawer design, the maintenance operator has access from three sides, which in itself makes for more flexibility in the arrangement of the equipment. The preferable direction of access is, of course, from the front since this generally borders on aisle space or space which is otherwise occupied by the equipment operator. The pull-out drawer design allows two or even three maintenance operators to work on the same shelf or rack simultaneously, which is often difficult or impossible when the operator must work inside the frame of the equipment. Note that it requires little more room at most, and generally <u>less</u> room, to work on arrangement A than arrangement B.



Ⓐ Ⓑ

b. additional space requirements

When work on an entire subsystem of an equipment is necessary (maintenance problems cannot always be solved by simple replacement, repair, or adjustment of components), it may be necessary to remove major portions of the equipment, or even the entire unit. With increasing electronic complications, it is often more expedient to remove and replace the entire rack (shelf or drawer) which contains the source of malfunction, and replace it with a ready spare. This may require additional clearance room beyond that required for ordinary maintenance. It is necessary to include in the equipment specifications not only the clearance room for removal of the rack or chassis, but also the room necessary for "man handling" and for special handling equipment, such as hoists, dollies, used for removal and replacement.* Additional space may also be required where ladders or frames are used to reach high and inaccessible places on the equipment.

2.4.4 Layout Models

This section discusses briefly the advantages of three-dimensional models. It is urged that, in the use of these small-scale models, the various necessary clearances be added to at least the major items of equipment. These include clearances for:

Operation and maintenance

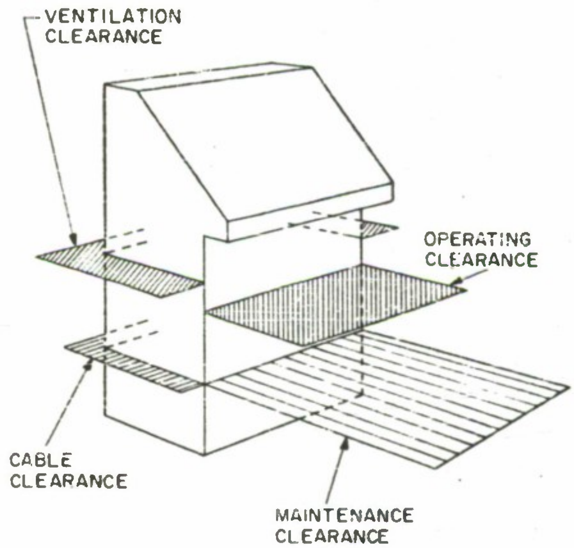
and where feasible†

Ventilation

Cables

Shock mounting

The clearances can generally be outlined by scale templates or skirts of a transparent material which can be affixed to the equipment. The edges can be touched with paint to color code the types of clearance represented.



* This is another example of the need for developing the maintenance tools, procedures, and related clearance tolerances concomitantly with the major equipment so that these can be written into the equipment specifications at least by the time of delivery of the model for field testing.

†Some of these requirements may be too complex in outline to duplicate.

These recommended additions to the models should be made with the primary purposes of the models in mind: low expense, portability, and ruggedness sufficient to withstand handling by the different interviewees and other observers who will be called upon to view the scale layout.

2.4.5 Aisle Space

In most layout arrangements, the aisle serves double duty as both traffic room and maintenance room. In general, since traffic is flexible (adaptable) and maintenance is done only occasionally, the regular aisle dimensions are designed only for the traffic flow. If possible, where maintenance operations encroach on frequently used aisle space and no alternate access space for rerouting traffic is available, additional space should be provided in that area; i.e., aisle space plus maintenance room should be furnished. The alternative is to schedule maintenance during the periods of minimum traffic flow. Sections 2.4.1 and 2.4.2 describe the necessary clearance which should be reserved for maintenance operations.

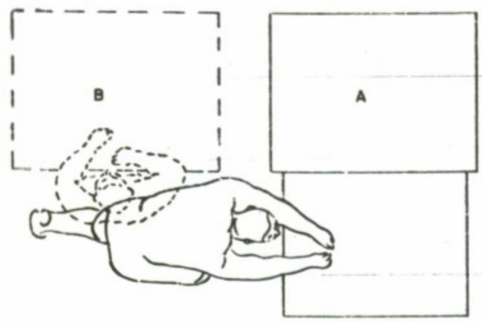
2.4.6 Interaction Between Equipment Units

The maintenance access requirements are of primary importance both for placement of equipment and in initial design considerations.

In laying out equipment, full advantage should be taken of the possibility of combining or "pooling" the various necessary clearances. For instance, an item of equipment may require 4 inches clearance for ventilation at the sides if placed against a bulkhead. If placed against another heat-producing item of equipment, it may require an additional 4 inches of side clearance. By adding a few more inches, sufficient room may be gained to allow maintenance at the sides of each piece of equipment.

An obvious combination is where two items of equipment each require 28 inches side clearance access for maintenance. A single 28-inch space will suffice for both units if placed side by side. Aisle space is usually always available for maintenance space, provided clearance is available for at least one-way traffic.

Design of maintenance access should take into account the position of the operators of adjacent equipment. Thus, the operator repairing console A is stationed correctly if the area in which he is kneeling is aisle space. However, if a console is in position B with an operator stationed in front of it, there is interference between the two men. When two or more units of equipment operate interdependently (e.g., if console A receives inputs from console B or otherwise depends on B for its proper functioning) so that both are out of operation simultaneously, the layout design can take advantage of this by placing them together.



With electronic complexity constantly on the increase, maintenance scheduling is certain to become of equal importance with operating characteristics (such as ease of operation clear vision) as a primary consideration governing equipment layout. A complex system will demand that preventive maintenance (such as routine parts replacement) take place according to strict schedule in order to prevent breakdown. While the mathematics and techniques necessary to determine this scheduling are beyond the scope of this chapter, it should be pointed out that the schedule may have an important bearing on placement of equipment; for instance, it may be undesirable to place together two units which demand frequent maintenance. In addition to the above considerations, planning of aisle space must also take into account the auxiliary equipment units which may be needed — dollies, mobile test racks, portable hoists, etc. — which may be stationed next to the equipment undergoing maintenance. (See also Section 1.3.)

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